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U.S. ARMY ENGINEER DISTRICT PHILADELPHIA
U.S. ARMY ENGINEER DIV. • NORTH ATLANTIC

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DELAWARE RIVER BASIN REPORT

DEC. 1960

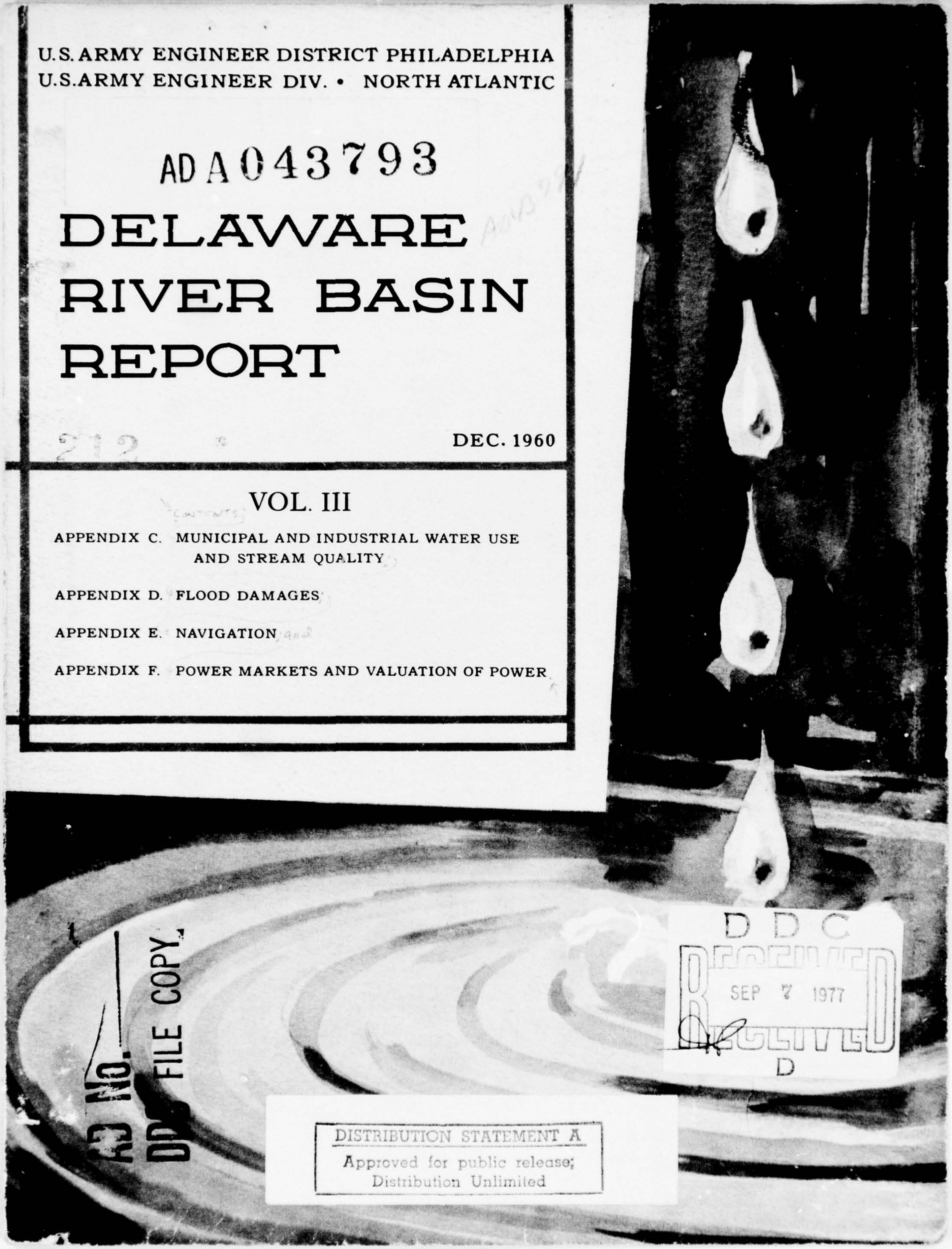
VOL. III

APPENDIX C. MUNICIPAL AND INDUSTRIAL WATER USE AND STREAM QUALITY

APPENDIX D. FLOOD DAMAGES

APPENDIX E. NAVIGATION

APPENDIX F. POWER MARKETS AND VALUATION OF POWER



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REPORT ON THE

COMPREHENSIVE SURVEY

OF THE

Water Resources of the

DELAWARE RIVER BASIN.

Volume III.

APPENDIX C thru F.

MUNICIPAL AND INDUSTRIAL WATER USE
AND STREAM QUALITY

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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FOR

U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLES

PART A

MUNICIPAL AND INDUSTRIAL WATER USE

TABLES (Cont.)

TABLES (Cont.)

FIGURES

Page

PART A

MUNICIPAL AND INDUSTRIAL WATER USE

PART B

STREAM QUALITY

FIGURES (Cont.)

FIGURES (Cont.)

SUMMARY

AND

RECOMMENDATIONS

SUMMARY

Part A - Municipal and Industrial Water Use

a. Municipal water use in 1955 The waters of the Delaware River basin provided the municipal water supply of 700 million gallons per day for a population of about 5,000,000 persons residing within the basin. In addition, the City of New York and the northern New Jersey metropolitan areas withdrew surface waters from the basin to serve a population of 2,440,000. This total population of 7,500,000 used an average of 1,074,000,000 gallons of water per day. In the larger Delaware River Service Area which also includes the greater New York City Metropolitan areas as well as contiguous portions of those basin counties lying outside the basin boundary, the total municipal water use averaged 2,697,900,000 gallons of water per day for a population of 20,383,800.

b. The per capita use of municipal water supplies within the basin averaged 141 gallons per day and within the Service Area, averaged 132 gallons per day reflecting the national water use pattern of 140 gallons per day. Surface waters are the source of seventy-nine percent (79%) of the total municipal supplies in the service area. Eighty-six percent (86%) of the total water used was supplied from publicly owned facilities. A similar pattern of source and ownership existed within the basin.

c. Quality of municipal and industrial supplies The quality of the municipal and industrial supplies is generally good. However, in the downstream areas more extensive water treatment measures are required to remove the impurities in the water resulting from the cumulative use of the basin waters by municipalities and industries. The waters of the upper basin diverted by New York City receive only minimal treatment of sedimentation and chlorination whereas the waters withdrawn from the lower Delaware by Philadelphia receive a more complete treatment of coagulation, sedimentation, filtration and chlorination.

d. Self-supplied industrial water use in 1955 Industry withdrew an average of 1,923,000,000 gallons of water a day. In addition, an estimated 3,406,000,000 gallons per day was withdrawn for cooling purposes by steam electric generating stations located within the basin. Industrial use of water in the portion of the Service Area lying outside the basin was not included in this study. The total industrial withdrawal of water was more than seven times the municipal withdrawal. However, included in the municipal use is 176 million gallons per day supplied to industry or twenty five percent (25%) of the total municipal use. The total industrial use within the basin for all purposes was 5,500,000,000 gallons per day or ten times the 537,000,000 gallons per day delivered by municipal supplies for domestic and non-industrial purposes.

e. Industry is a major water user in the basin with the primary metal, chemical, and petroleum industries using the greatest quantities of water. Surface water represented ninety percent (90%) of the self-supplied industrial use including 160 million gallons per day of brackish waters and one hundred percent (100%) of the cooling water use by steam electric generation including 655 million gallons per day of brackish waters.

f. The total municipal and industrial water use for the Delaware River basin in 1955 was six billion gallons per day serving a population of five million. For the basin this represents a withdrawal rate of 0.5 million gallons per square mile of basin area, a rate of withdrawal more than twelve times that for the United States as a whole. This is indicative of the intensity of water use in the basin.

Part B - Stream Quality

g. Stream Quality from Headwaters to Trenton, New Jersey The headwaters of the Delaware basin and the waters in the area from Port Jervis to approximately Easton, Pa. are generally of excellent quality and capable of supporting a variety of uses. Increased population densities and industrialization in the vicinity of Easton, Pa. and in the Lehigh Valley result in a slight degradation in the quality of the Delaware River below the confluence of the Lehigh River. Average summer dissolved oxygen levels during 1957 decreased from approximately

8.5 ppm immediately above Easton to 7.4 ppm below Easton. From Easton, Pa. downstream to Trenton, N. J., the Delaware River receives waste discharges from various communities and industries equivalent to a population of 143,000. Natural leaching and erosion products in addition to the pollution load carried by the stream require increased water treatment by municipal and industrial users in this reach. Average monthly hardness of the mainstream at Trenton during the summer months from 1951-1955 was approximately 80 ppm. Average monthly total iron at Trenton during the summer months from 1948-1955 was approximately 0.45 ppm. For the same period the turbidity was low approximating 25 ppm. Construction of dams and reservoirs in upstream areas recently have temporarily increased the turbidity.

h. Trends in Waste Loading and Stream Quality of the Delaware Basin from its Headwaters to Trenton, N. J. In 1950 a population of 631,000 (in the area considered tributary to the Delaware River) after treatment contributed a pollution load to the Delaware River equivalent to a population of 220,000. A decline in pollution load occurred thereafter as a result of the installation of major treatment works. By 1957 a population of 681,000 contributed a pollution load equivalent to a population of 143,000. Approximately 50% of this tributary population was served by sewer systems. Of these 341,600 people, 96% were served by facilities providing secondary sewage treatment. It is estimated that the population of the tributary area will increase to 765,000 in 1965, 927,000 in 1980 and 1,400,000 in 2010. This increase in population is expected to result in the following changes in pollution loadings to the Delaware River.

(a) The pollution load will continue to decrease until approximately 1962, as a result of the installation and expansion of sewage treatment facilities serving the populations presently sewered at which time it is estimated that the load will be equivalent to a population of 135,000.

(b) It is expected that after 1962 the rise in population will surpass sewage treatment plant construction resulting in a gradual increase in the pollution load to the stream.

(c) The continuing rise in population will necessitate the sewering of populations which previously utilized individual means of sewage disposal. This will result in pollution loadings to the stream (regardless of the extent of treatment) where none existed in the past. It is expected that the rate of increase in pollution loading will soon approach the rate of increase in population and by 1980 the total pollution load discharged to the Delaware River will be at the same level as that in 1950, equivalent to a population of approximately 220,000. By 2010, it is estimated that the total load to the Delaware between Port Jervis and Trenton will be equivalent to a population of about 300,000.

i. From an examination of stream quality conditions as determined by surveys made in 1929 and in 1957, it is concluded that the increase in pollution load discussed above will not decrease the average dissolved oxygen content of the Delaware River from the headwaters to Trenton below the present level of 7.0 ppm. The change in quality over the twenty-eight year period (1929-1957) has been negligible. At no time during these surveys has the average dissolved oxygen fallen below 7.0 ppm. Hence, it is expected that until 1980 there will be no change in water quality which may influence water uses in this reach of the Delaware River. For the period ending in 2010, it is anticipated that the dissolved oxygen content at the critical point (vicinity of Milford, N. J.) may fall to as low as 5 ppm and possibly at times may fall below this figure. In general, however, the Delaware River from its headwaters to Trenton can still be expected to support a wide variety of water uses during the period ending in 2010.

j. Stream Quality from Trenton, N. J. to Delaware Bay The dissolved oxygen content of the tidal portion of the Delaware River has been used as the primary indicator of stream quality. Dissolved oxygen data collected over a nine year period (1949-1958) by several governmental agencies was analyzed and the following conclusions were drawn:

(a) The predicted average dissolved oxygen over this nine year period ranged from a high of 9.4 ppm at Burlington Bristol Bridge to a low of 4.0 ppm at Marcus Hook.

(b) The minimum average daily dissolved oxygen content varied from 6.4 ppm at Burlington Bristol Bridge to 0.6 ppm at Marcus Hook.

(c) Depending on the time of tide and the time of the day considerable variations in dissolved oxygen were experienced within the day during which the minimum average daily dissolved oxygen occurred. These variations resulted in extreme minimum dissolved oxygen values during a day ranging from 5.1 ppm at Burlington Bristol Bridge to 0.0 ppm at Marcus Hook.

k. Trends in Waste Loading and Stream Quality of the Delaware River from Trenton, N. J. to Delaware Bay The trends in population contributing to the municipal pollution load of the tidal portion of the Delaware River have been determined for eight principal areas accounting for 94% of the total municipal load presently discharged into the estuary. It is anticipated that the population of these areas will increase from 2,880,000 in 1958 to 3,880,000 in 1965 and 4,120,000 in 1980. It is estimated that sewage treatment facilities will remove the additional load contributed by the increased population by increasing the efficiency of treatment from the 1958 level of about 40% to 50% in 1965 and holding at this level until 1980. This increase assumes increased interception of wastes presently discharging to the estuary without treatment. The present level of overall removal of potential pollution load is about 32%. The 40% removal thus represents the efficiency of treatment plants in removing the load which arrives at the plant and not the total load which may originate from a given area. Industrial loadings to the estuary have been assumed to increase linearly at approximately the same rate as the population increase. The total pollution load to the Delaware estuary decreased from about 5,300,000 population equivalent in 1950 to 4,600,000 population equivalents in 1958. It is anticipated that the total pollution load discharged into the estuary in 1965 will be at the same level as that in 1958 and by 1980 will increase to a load equivalent to a population of approximately 5,600,000 people or slightly higher than the level experienced in 1950.

l. The year to year changes in annual average dissolved oxygen do not indicate any straightline trend. Annual average dissolved oxygen concentrations at three stations (Torresdale, Benjamin

Franklin Bridge and Marcus Hook) fell to as low a level in 1957 as in 1939 although the change in pollution load to the stream decreased from a population equivalent of 6,000,000 in 1939 to 4,600,000 in 1958. Apparently, the magnitude of the pollution load over the past twenty years has remained at a level which has provided essentially a status quo situation in dissolved oxygen. The expansion of sewage treatment facilities has undoubtedly prevented a degradation of the dissolved oxygen levels. Annual average water temperatures during 1950-1957 have varied only slightly. The changes in annual average dissolved oxygen which occurred were considerably larger than if the changes were due to the variations in annual water temperature alone. The annual average dissolved oxygen during 1950-1957 correlated significantly with the average minimum three month fresh water inflow at Trenton. Therefore it was concluded that the changes in annual average dissolved oxygen during 1950-1957 were primarily a result of the changes in the fresh water flow. Further, the changes in dissolved oxygen <u>within</u> any year during 1950-1957 were affected by the changes in fresh water flow. It is recognized that these changes in dissolved oxygen <u>within</u> a year are also a result of the changes in water temperature and pollution load. However, it is expected that within any given year the pollution load will remain fairly constant thereby affecting the changes in dissolved oxygen within a year to only a slight extent. Separation of the independent influence of temperature and flow on the variation of dissolved oxygen within a year was not attempted.

m. Since the decrease in pollution loading accomplished during 1950-1957 did not materially affect the dissolved oxygen, the increase in loading for the period ending in 1980, to a level approximately the same as in 1950, will not materially affect the dissolved oxygen levels already established. As indicated previously it is believed that the year to year changes in annual average dissolved oxygen which occurred during 1950-1957 were primarily a result of changes in fresh water inflow. Therefore it was concluded that any future changes in annual average dissolved oxygen will be due primarily to changes in fresh water inflow. It was also concluded that since the changes in annual average dissolved oxygen during 1950-1957 were primarily a result of fresh water inflow, the changes in dissolved oxygen <u>within</u> a year were also affected by the fresh water inflow as well as by water temperature. Since the future changes in annual average dissolved

oxygen will be mainly a result of fresh water inflow it is expected that until 1980 the changes in dissolved oxygen within a year will be primarily a result of changes in fresh water inflow and water temperature.

n. The changes in dissolved oxygen within the average year during 1950-1957 are described (as illustrated in paragraphs j.(a), (b) and (c)) using statistical methods. The results of the use of these methods indicate that the dissolved oxygen during any time of year, day or tide can be computed with a high degree of confidence. Since these changes in dissolved oxygen were a result of the same factors which are expected to influence the change within future years, it is expected that the changes that have occurred within the average year during 1950-1957 will remain essentially the same throughout the period ending in 1980. It is therefore anticipated that the description of the dissolved oxygen within the average year during 1950-1957 (as determined by the statistical analysis) will continue to be applicable until 1980.

o. For the period ending in 2010, it is estimated that the total pollution load to the estuary will be equivalent to a population ranging from 5,400,000 to 8,400,000. The lower figure assumes an increase to 70% in overall removal efficiency and the higher figure assumes removal efficiencies at present levels. The resulting water quality from this range in load will be between the conditions which existed in 1940 and those which existed in 1950 although increasing industrial technologies may create quality problems heretofore unrecognized. Should substantial pollution removal not be accomplished, the quality of the estuary will progressively deteriorate to the level which existed in 1940. However, the efforts of the various water pollution control agencies which have been so effective in the past can be assumed to continue and it does not appear that quality conditions will be allowed to retrogress to the level of twenty years ago.

Part C - Effects of Comprehensive Plan

p. Water quality in proposed impoundments It is expected that the water in the impoundments proposed in Appendix Q will be of high quality. This will not preclude the need for treatment of withdrawals made directly from the reservoir or of wastes discharged

directly to the pool or to tributaries thereof. The firm policies which already exist in all the States requiring water and waste treatment can be assumed to apply in the future.

q. It is anticipated that stratification of temperature will occur in varying degrees in all of the major impoundments. The formation of a thermocline in the deeper pools will lead to dissolved oxygen stratification. The extent of the thermocline and subsequent dissolved oxygen stratification is in part dependent upon the type and operation of outlet structures. At Tocks Island and with surface level intakes, the development of a thermocline at a depth of 40-50 feet will result in a $1^{o}C$ - $2^{o}C$ difference between the temperature of the incoming flow and the temperature of the discharged water during approximately August to October. With intakes withdrawing from the surface layers, the dissolved oxygen of the discharged water will be essentially the same as that of the incoming flow, ranging from super-saturation values of 14 ppm to a low of 7.0 ppm. If lower level intakes are provided, the temperature of the discharged water will usually be from $10^{o}C$ - $14^{o}C$ during the summer months. During this time the dissolved oxygen of the discharged water will become progressively lower until late in the summer when the water may be completely devoid of dissolved oxygen. It is expected that the other major control projects proposed for the upper headwaters of the Delaware basin and the Lehigh and Schuylkill basins will follow similar patterns of temperature and dissolved oxygen stratification. The concentrations of other water quality characteristics such as hardness, turbidity, bacterial content, etc. will not be excessive.

r. At one site, Newtown (presently proposed for single purpose recreational use) a water quality problem may exist. The discharge of treated sewage equivalent to a population of about 3,000 above the site indicates the need for further investigations prior to the initiation of this project.

s. State policies on waste treatment New Jersey and Pennsylvania have indicated that low flow augmentation will not be accepted in lieu of required degrees of treatment which for the Delaware basin above Trenton has been established by Incodel as a minimum of secondary treatment. New York considers each stream individually. However, only one project (Hawk Mountain) will be located in New York and it is not

estimated to result in any change in waste treatment measures downstream. Delaware has indicated that it will not require a degree of treatment higher than primary. These State policies together with the required degrees of treatment and the expected effect of low flow augmentation will not result in any changes in the degree of waste treatment as a result of the Comprehensive Plan.

t. Effects of impoundments on stream quality from headwaters to Trenton, N. J. The regulated flow of 4060 cfs proposed for the Delaware River by 1980 will not result in tangible waste treatment benefits. Even without low flow augmentation the minimum 1980 dissolved oxygen level is not anticipated to drop below an average of 5.0 ppm and may not even drop below the present average level of 7.0 ppm. Since secondary treatment of wastes is already required by Incodel and New Jersey and Pennsylvania and since it is not anticipated that stream quality problems will develop even without low flow augmentation, no changes or deferrals of the degree of waste treatment are expected to occur as a result of the major control projects of the Comprehensive Plan. A reduction in the mean monthly hardness content at Trenton is expected in 1980 for the regulated flow of 4060 cfs. This reduction in hardness will in part be offset by an anticipated increase in average monthly total iron concentration. Large temporary increases in turbidity of four to five times the normal levels of 10-20 ppm will occur immediately below each site due to normal construction activities and may persist in varying intensities for some distance downstream.

u. For the period ending in 2010, it is anticipated that irrespective of low flow augmentation, the stream quality is expected to be within acceptable limits. Hence, the addition of flow to the natural minimum flow will not produce any changes in the required secondary degree of treatment since there essentially will not be any stream quality problem. With no changes in waste treatment measures anticipated resulting from low flow augmentation, no benefits can be ascribed.

v. Although no large tangible stream quality benefits will accrue from the Plan during the period ending in 2010, it is expected that with increasing pollution loads, the beneficial effects of the Plan will become more and more pronounced during the 50 years following 2010. The stream quality of the Delaware above Trenton may then

be prevented from potentially deteriorating further by the augmentation of low flows. Qualitatively, the effects of the major control projects on stream quality during the period following 2010 will assume a relatively greater importance and more tangible benefits will result.

w. Effects on downstream quality from Trenton to Delaware Bay It is estimated that for the Delaware River above the Delaware State line, a small increase in dissolved oxygen of about 1 - 1.5 ppm will occur as a result of a regulated flow of 4060 cfs in 1980. However, a decrease in dissolved oxygen of about 0.3 - 0.4 ppm is expected to occur below the Delaware State line. The increase in dissolved oxygen above the State line is not sufficient to warrant any changes or deferrals in the degrees of waste treatment required by the States and Incodel. Further, the anticipated decrease in dissolved oxygen is not expected at this time to result in increased waste treatment by Delaware. It is believed that for the entire estuary, a net intangible benefit will occur where the increase in quality above the State line would outweigh the decrease in quality below the State line.

x. Although it is anticipated that the quality of the estuary in 2010 will be somewhat less than at present, it is believed that the increase in augmented flow from 4060 cfs in 1980 to 4720 cfs in 2010 will not result in a further significant increase or decrease in dissolved oxygen. It is not expected then that the increase in fresh water flow augmentation will change the dissolved oxygen levels to such an extent that additional sewage treatment facilities can be deferred. The quality of the estuary can be maintained at least at present levels only by substantial increases in waste treatment measures. Low flow augmentation will supplement the waste treatment programs, but it is estimated that the quality of the estuary will not be altered materially by the proposed magnitude of the regulation of fresh water inflow. A tangible monetary benefit cannot therefore be ascribed to the increase in flow, although an intangible supplemental benefit should be recognized.

y. For the period beyond 2010, low flow augmentation may assume a more important role in the maintenance of the quality of the estuary. The installation of even higher degrees of treatment above secondary may possibly be forestalled for a period of time. However,

it should be recognized that conditions below the State line may deteri-
crate even further which may result in the need for increased treatment in Delaware as a partial result of low flow augmentation. Whether the balance between these two factors will be favorable or unfavorable is extremely difficult to determine at this time. This determination should be made at the appropriate time in the future so that the longer range effects of the Comprehensive Plan can be evaluated more precisely.

RECOMMENDATIONS

a. The following recommendations with respect to water use and stream quality are offered for the efficient implementation of the Comprehensive Plan for the control of Water Resources in the Delaware Basin:

(1) Studies should be performed before, during, and after the construction of the contemplated dam and reservoir projects in order to obtain quantitive information with respect to the effects of the impoundments on water quality and subsequent water use. The determination of these effects will be of considerable value in the detailed planning of additional projects in the basin.

(2) Investigations should be made not only to determine the causes and effects of water quality stratification in the proposed reservoirs, but also the design modifications necessary to eliminate or control stratification.

(3) A more adequate basic data program should be instituted in order to provide additional information to aid in the above studies and to provide more accurate bases for future predictions of water use and stream quality to be used in evaluating the needs for increased stream flows. This program should include collection of detailed data on all aspects of municipal and industrial water use and water treatment, and waste disposal in order to more accurately assess the needs occasioned by future industrial and municipal expansion. Likewise, a network of monitoring stations to measure all aspects of stream quality is necessary.

(4) For the efficient utilization of the data a central depository should be initiated where all basic data of common interest in water resources development would be referred for compilation and reduction. Further, the responsibility for the continuous collection of all of these basic data should be undertaken on a cooperative basis by those Federal, state and local agencies concerned with this need.

(5) Continuation of the effective water pollution control and abatement programs of New York, New Jersey, Pennsylvania and Delaware and the Interstate Commission on the Delaware River is required.

Undoubtedly, without the effective activities of these agencies in the past, the quality of the waters of the Delaware River basin would have been even more seriously impaired in many areas to the point where limitation of legitimate water uses, and therefore limitation of economic growth would have occurred even more than it has. In the future, the need for such programs will be even more imperative.

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PART A

MUNICIPAL AND INDUSTRIAL WATER USE

PART A

MUNICIPAL AND INDUSTRIAL WATER USE

CONTENTS

SECTION I - FOREWORD

Scope

1. Purpose The purpose of this report is to demonstrate the present qualitative and quantitative utilization of Delaware River basin water resources for municipal and industrial water supplies. To accomplish this it is necessary to develop an overall assessment of present water requirements of the basin and the Service Area (the non-basin areas considered to be dependent upon the basin for water resources presently and in the foreseeable future). These data will be the basis for the projections of future water demands necessary for the intelligent planning of water resources and the corollary development and evaluation of the Comprehensive Plan.

2. Organization The report is organized into nine sections in order to realize this purpose. Following this foreword, the second section contains a discussion of the historical development of water resources, with particular reference to municipal and industrial use. The quality and quantity relationships and the utilization of municipal supplies are discussed on geographic and other bases in the third and fourth sections. A similar treatment is then accorded the industrial water use in sections five and six. Then the municipal and industrial water use are summed in the next section in order to present the total existing water requirements of the area. Finally, sections eight and nine discuss the water supplies of Philadelphia and New York, the two largest cities dependent upon the Delaware River.

Acknowledgements

3. Cooperating Agencies The Public Health Service wishes to express its appreciation for the cooperation and assistance given to them in this study by the many Federal, interstate, state, local governmental agencies and a number of private and advisory organizations. Also acknowledged is the assistance given by members of the Water Supply Work Group in the review and preparation of this report. The

member agencies are listed below:

Federal Agencies:
  Department of Agriculture
  Department of the Army
    U.S. Army Engineer District, Philadelphia
  Department of the Interior
    U.S. Fish and Wildlife Service
    U.S. Geological Survey

Interstate Agencies:
  Interstate Commission on the Delaware River Basin

State Agencies:
  Delaware
    Board of Health
  New Jersey
    Department of Conservation & Economic Development
    Department of Health
  New York
    Department of Health
    Water Power & Control Commission
  Pennsylvania
    Department of Forests and Waters
    Department of Health

Municipal Agencies:
  New York City
    Board of Water Supply
  Philadelphia
    Department of Water
    Department of Public Health

SECTION II - INTRODUCTION

Delaware River Basin - Main Stream

4. Above Port Jervis, N.Y. The upper section of the basin's 12,760 square miles is renowned for its scenic beauty, recreational assets and use as a source of municipal water supply. The section above Port Jervis is a largely forested, mountainous area with swiftly flowing streams. The Catskill Mountains in the northeastern part rise to an elevation of about 3,500 feet above sea level, and the Pocono Mountains lying to the southwest in Pennsylvania rise to an elevation of about 2,000 feet.

5. Below Port Jervis, N.Y. Between Port Jervis and the Delaware Water Gap, the tributary rivers and valleys extend generally in a northeast-southwest direction with the main river channel piercing the ridges to form canyon-like gaps. The river cuts the Kittatinny Mountains at the Delaware Water Gap, providing exceptional scenic views. Below the Gap the Delaware meanders through lower lands, receiving the waters of the Lehigh River at Easton, and then cutting southeasterly across various rock ridges to an elevation of 40 feet, immediately above Trenton Falls, before passing into the tidal area below Trenton. The river finally widens into Delaware Bay at Liston Point.

6. Geology The watershed of the Delaware River lies within five of the major geological provinces of the eastern United States: the Interior Plateau above Port Jervis, the Appalachian Folds extending from Port Jervis to the Delaware Water Gap, the Taconic Deformation Belt from the Delaware Water Gap to Easton, the Atlantic Highlands from Easton to Riegelsville and the Atlantic Coastal Plain from Trenton to the sea. The principal tributaries of the Upper Delaware are:

a. The Mongaup Valley which lies entirely within the Interior Plateau
b. The Neversink which lies principally within the plateau and enters the Appalachian Folds in its lower reaches
c. The Lackawaxen River and Shohola Creek which are

entirely within the Pocono Region of the Interior Plateau

d. The Lehigh River which rises in the Interior Plateau with its headwaters in the Pocono Mountains and which cuts through the Appalachian Folds between White Haven and Lehigh Gap, traversing the Taconic Deformation Belt to Allentown, and then following the borderline between this belt and the formations of the Atlantic Highlands to Easton.

7. The underlying formations on the Pennsylvania side of the river are trap, sandstone, schist, shale and gneiss. The New Jersey side is composed of sand and gravel. The open land is well adapted to agriculture and is intensively farmed. The lower portion of the basin is highly industrialized. Most of Delaware and lower New Jersey in the Bay region are part of the Coastal Plain and consist of low, flat land with few hills as high as 100 feet above sea level. Details of the geology of the area are discussed in the Appendix prepared by the U.S. Geological Survey.

Schuylkill River Sub-Basin

8. Above Reading, Pa. The Schuylkill River is the largest tributary of the Delaware River entering it at Philadelphia. The Schuylkill River basin comprises approximately 1,900 square miles of the lower Delaware watershed in southeastern Pennsylvania. It is about 93 air miles long, averages 21 miles in width and comprises approximately 15% of the drainage area of the Delaware River basin. The river rises in the upper portion of the Schuylkill County, about 150 river miles above its confluence with the Delaware River. It flows southeastwardly through the mountainous coal regions for about 25 miles. There it is joined by the West Branch, which has its origin in the mountains above Minersville, and later, by the Little Schuylkill, which originates to the east above Tamaqua and Lansford. As it passes below Schuylkill Haven, the Schuylkill cuts through the Blue Mountain range producing a gap similar in many respects to the renowned Delaware Water Gap.

9. Below Reading, Pa. The Schuylkill enters Berks County above Reading where it is joined by Maiden and Tulpehocken Creeks. As it winds through the rolling hills below Reading, the Schuylkill is joined by a number of tributaries: Manatawny, French, Perkiomen, Pickering and Wissahikon Creeks. At Pottstown, the Schuylkill becomes the boundary between Montgomery and Chester Counties. The tidal section is within the City of Philadelphia. Elevations range from tide water in the tidal marshes at the confluence with the Delaware to 1,800 feet in the mountainous coal regions of the headwaters.

10. Geology The major portion of the southern Pennsylvania anthracite field lies within the upper Schuylkill River basin. Southeast of Blue Mountain, the watershed is located in the Appalachian Valley and in the relatively modern Atlantic Coastal Plain. The lower Schuylkill River basin is open land, well adapted to agriculture, a large part of which is presently being farmed while a smaller area is devoted to woodland. Details of the geology of the area are discussed in the Appendix prepared by the U. S. Geological Survey.

History of Basin Development

11. General needs The Delaware and its tributaries, one of the most coveted sources of water in the eastern United States, supplies many millions of people with water. For the past forty years, an area containing one-eighth of the total population of the United States, including the metropolitan regions of New York, northeastern New Jersey and Philadelphia, have been continually confronted with water supply problems. All have looked to the Delaware for a solution to their needs.

12. A resume of municipal water supply proposals and developments, stream regulation and hydroelectric proposals will serve to illustrate the degree of competition for Delaware River water by the various interests in the basin and in the adjacent metropolitan areas of New York and northeastern New Jersey.

13. New York City proposals Before New York City's Catskill water supply system had been fully completed in 1928, it was realized that the City should start preparing further additions to its water supply. The new Catskill system added to the Croton Reservoir system plus existing local ground water supplies gave a dependable yield of only approximately one billion gallons per day (gpd). An analysis of all other available sources of water supply for New York City led to the selection of Rondout Creek, a tributary of the Hudson River, and certain of the upper tributaries of the Delaware within the State of New York.

14. First plan This plan, approved by the New York State Water Power and Control Commission in 1929, provided for the development of new sources in three stages:

First Stage -- Rondout Creek (a tributary of the Hudson) and the Neversink River (a tributary of the Delaware)

Second Stage -- East Branch of the Delaware

Third Stage -- Little Delaware River, Willowemoc Creek and Beaver Kill (all tributaries of the Delaware)

It was estimated that the entire project could be completed in 1939 and would provide 700 million gallons per day (mgd), 600 of which would come from tributaries of the Delaware.

15. Supreme Court action The State of New Jersey promptly applied to the Supreme Court of the United States to enjoin the State and City of New York from diverting any of the waters of the Delaware or its tributaries. New Jersey contended that the diversion would cause substantial damage to navigation, water power, sanitary condition of the River, industrial use, the oyster and shad fisheries, municipal water supplies, agricultural lands and recreation. Pennsylvania became a party to the suit as intervenor to protect its rights to the Delaware River as a future water supply source. The case was heard by a Special Master whose findings were approved by the

Supreme Court on May 25, 1931. This decision (a) limited the City of New York to a diversion of 440 mgd instead of the 600 mgd requested, (b) required that New York release from the reservoir a limited quantity of water to maintain certain minimum flows at Port Jervis or Trenton, and (c) required the construction of an effective sewage treatment plant for Port Jervis before any diversion could be made.

16. Revised plan Construction of New York City's first three impounding reservoirs (Pepacton Reservoir on the East Branch, Neversink Reservoir and Rondout Reservoir), was not started until 1937 due to the litigation and the depression years of the 1930's. By 1943 construction was again halted because of World War II. Fortunately, the Delaware Aqueduct had been substantially completed, and temporary measures enabled the ordinary unimpounded stream flow of Rondout Creek to be delivered to the water system. Work was resumed in 1946 and the first stage, including the Rondout and Neversink Reservoirs, was completed in 1954. The second stage of the Delaware project - the Pepacton Reservoir and connecting tunnel - was placed in operation in 1955. With the completion of this project New York was able to utilize the 440 mgd authorized from the Delaware under the 1931 decree (335 mgd from Pepacton and 105 mgd from the Neversink Reservoir).

17. The Supreme Court case, the depression in the early 1930's and the halting of construction during World War II, caused a total delay of 14 years. If construction of the Delaware project had been completed on schedule, the water shortage in New York City during the 1949 drought would have been avoided.

18. Final plan New York City, at the beginning of 1950, took an additional step to insure an adequate water supply for the future. Approval was secured from the Board of Estimate at that time to proceed with a revised plan for the third stage of the Delaware project. This included a reservoir at Cannonsville on the West Branch from which about 312 mgd would be utilized. In addition, the City requested the Supreme Court to allow an additional 48 mgd diversion from the Neversink and East Branch Reservoirs, or a total of 360 mgd above 440 mgd then permitted to be taken from Delaware tributaries.

	First Plan (mgd)	Requested Additions (mgd)	Revised Plan (mgd)
Neversink	105	48	448
East Branch	335		
West Branch	---	312	312
TOTAL	440	360	800

The New York State Water Power and Control Commission granted approval for this plan in November, 1950, contingent upon the United States Supreme Court modification of the existing restrictions, upon other requirements concerning water releases and the construction of dams on the tributaries.

19. Supreme Court decision On June 7, 1954 the Supreme Court of the United States approved the diversion of 800 mgd by the City of New York from the Delaware River headwaters providing that the City of New York make certain compensatory releases. Construction has been started to obtain the added diversions authorized by the Supreme Court. It is expected that the Cannonsville Reservoir will be completed about 1963.

20. INCODEL The above competition for water led the States in which the Delaware River watershed is located to attempt to plan cooperatively, the better utilization of the natural resources of the Delaware. Therefore, in 1936, the Interstate Commission on the Delaware River basin (INCODEL) was formed as an interstate agency ". . . engaged in the formulation and execution of a coordinated, unified plan looking toward wise use, development and control of the natural resources of the Delaware River basin as a whole." INCODEL began to formulate a unified plan for the development of the resources of the basin in 1937. In undertaking this responsibility INCODEL decided that its initial objective should be to resolve major problems, such as stream pollution control. Under the impetus of INCODEL, each of the four states enacted reciprocal legislation known as the INCODEL Act for the abatement and control of stream

pollution in the Delaware basin. This legislation: (a) established the four zones of the Delaware River, (b) set forth the minimum degree of treatment for wastes discharged into each of these four zones and (c) designated the principal water uses for these zones.

21. INCODEL plan. Late in 1950 INCODEL presented its Report on the Utilization of the Waters of the Delaware River Basin, which introduced an integrated plan for water supply development and flow regulation of the entire Delaware River basin. Two alternate plans were suggested, depending upon the method of supplying Philadelphia and the adjacent metropolitan area with additional municipal and industrial water. The INCODEL plan to serve the needs of the four-state area was designed to be constructed in two or more stages.

22. The first stage was designed to provide up to 465 mgd (in addition to the 440 mgd previously granted by the Supreme Court) in order to meet the estimated additional requirements of the northern New Jersey and New York City areas for the next thirty years. The plan also provided for the storage of sufficient water to maintain a minimum flow in the Delaware River at Trenton of 4,000 cubic feet per second (cfs) without construction of a reservoir at Wallpack Bend, and 4,800 cfs with this reservoir. The second stage was to include two additional major reservoirs.

23. INCODEL Compact. In 1951 the proposed INCODEL Compact, a measure which would provide for an interstate agency to construct and operate the proposed INCODEL reservoir projects, was introduced into the legislatures of Delaware, New Jersey and New York. The Compact was passed in that same session by Delaware and New Jersey, but New York deferred passage until 1952, awaiting action by Pennsylvania. The Governor of Pennsylvania requested the Legislature delay considering the matter until a committee appointed by him had made an independent appraisal of the program. In 1951, a Water Resources Committee was named to examine the INCODEL plan for the purpose of determining whether Pennsylvania would be in a more favorable position under the plan than under the Supreme Court decree of 1931; to determine whether the plan or any modification would adequately protect the State's interest; and to conduct a preliminary study of untapped water resources available in Pennsylvania

in lieu of Delaware.

24. While the committee was conducting its survey in 1952, New York State passed the proposed INCODEL Compact. New York City, however, filed a petition to the Supreme Court in 1952 seeking approval to proceed with its independent plan for the development of Cannonsville Reservoir on the West Branch to secure additional water supply.

25. Pennsylvania water resources report In February, 1953, the Pennsylvania Water Resources Committee, on the basis of the Engineers Study Committee report, rejected the INCODEL plan. It was felt that Pennsylvania would not derive sufficiently important benefits from low flow augmentation to compensate for the total diversion by other states of an additional 930 mgd from the Delaware watershed. In addition, there was objection to the terms of the proposed INCODEL Compact regarding future water allocation to Pennsylvania.

26. Recommendations The report recommended that when Philadelphia and southeastern Pennsylvania find it necessary to go upland for their water supplies, Pennsylvania and New Jersey should enter into an agreement to construct Wallpack Bend Reservoir. Five additional projects were outlined, which could accomodate, with or without Wallpack Bend, the needs of greater Philadelphia and South Jersey for the foreseeable future.

27. In 1953 the New Jersey State Legislature enacted a law (Chapter 443, P.L. 1953) which partially repealed an 1873 statute that forbade the construction of dams across the Delaware River. The Commonwealth of Pennsylvania or its designee was given the right (for a period of 50 years) to construct a dam and reservoir across the Delaware River at or near Wallpack Bend, above the confluence with Flat Brook. The dam and reservoir would provide a ". . . supply of water for domestic, commercial and industrial purposes and compensation flow . . .," in exchange for the right of New Jersey to ". . . divert outside the Delaware River watershed from the Delaware River or its tributaries in New Jersey without compensation releases, the equivalent of 100 mgd." This was incorporated into the 1954 Decree of the U.S. Supreme Court.

28. Hydroelectric proposals At periodic intervals in recent years, private utility companies have filed applications with the Federal Power Commission for licenses to construct hydroelectric dams on the Delaware River between Port Jervis and Easton. In every instance, INCODEL and the States of New York, New Jersey and Pennsylvania have protested against the granting of such licenses. The contention is that no construction should be permitted on the River which would jeopardize the future development of the water resources of the Delaware River basin by the states for municipal water supply. It is understood that the existing and possible future hydroelectric development of the Delaware is being studied by the Federal Power Commission.

Water Uses

29. Variation in use The major beneficial uses of water are tabulated below. It should be noted that these uses are not necessarily listed in their order of economic or water quality importance.

a. Potable water supply
b. Industrial water supply
c. Agricultural water supply (irrigation)
d. Habitat of fish and other aquatic life (game and commercial fishing)
e. Recreation (excluding fishing)
f. Shellfish culture
g. Stock watering
h. Hydropower
i. Navigation
j. Waste disposal

30. Competition of use The relative importance of any of these uses depends upon the regional development, the economy of the area and the needs and desires of the population. As far as water quality is concerned, most of the uses listed may be enjoyed together and do not preclude other parallel uses. However, it is readily seen that extensive use of a stream for waste disposal might make it unsuitable for municipal and industrial water supply purposes. Multi-purpose use of streams has been achieved in some of the great western

river developments which furnish municipal and industrial water supplies, hydropower, irrigation water, habitat for fish life and recreational uses. The scope of the Public Health Service portion of the Delaware Water Resources Survey has been limited to a study of three of the above uses, i.e., municipal water supply, industrial water supply and waste disposal. Other water uses are discussed by the appropriate Federal agency in its Appendix.

31. Classification of uses - withdrawal Water uses may be generally classified as withdrawal and non-withdrawal types. Withdrawal uses are those uses in which the waters are removed from the ground or diverted from a stream or lake, e.g., municipal and industrial water supplies, irrigation, stock watering and rural domestic use. Non-withdrawal uses do not require diversion and are employed in place. Navigation, recreation, waste disposal and conservation of fish and wildlife are examples.

32. Classification of uses - consumptive Uses of water may be further classified as consumptive and non-consumptive. In consumptive use the water is not returned to its original source - for example, water incorporated into a product, used for irrigation or evaporated to the atmosphere. Water used for non-consumptive purposes is returned to its source - for example, much of the water used for municipal water supplies flows back to the streams as treated or untreated sewage. The water supply diversion of New York City, where water is taken from the Delaware watershed and not returned to it, is an example of a consumptive use so far as the Delaware basin is concerned.

33. Summary The use of water for domestic water supply is generally conceded to be the highest use of water. Within the context of this report, domestic and municipal water supply are practically one and the same since domestic use is by far the larger portion of municipal water supply use, and no differentiation can be made between them on the basis of quality. The upper Delaware is devoted primarily to this use. The Delaware River and its tributaries have had unusual demands placed upon them because they flow through and are adjacent to some of the most highly industrialized and urbanized portions of the country. The future holds little promise of respite, and it is likely that the future demand for water supply will be met principally from

headwater reservoir development.

Areas to Be Covered in This Report

34. Introduction A comprehensive treatment of water use requires a discussion of both the quality and quantity aspects. In order to make comparisons and projections of water use, it is necessary to develop municipal and industrial water requirements separately, since there is an overlap between these two aspects. Similarly, a summary of the total water use is required. Therefore, this portion of the study has been divided accordingly:

a. Municipal Water Quality (Section III)
b. Municipal Water Use (Section IV)
c. Industrial Water Quality (Section V)
d. Industrial Water Use (Section VI)
e. Total Municipal and Industrial Water Use (Section VII)

35. Municipal water quality Quality requirements for a public water supply must meet the public health and other needs of a community. These requirements are attainable by varying degrees of treatment of the water supply prior to its delivery to the consumer. The protection of public health requires the meeting of certain standards. One of these, the U.S. Public Health Service Drinking Water Standards, is given as an example. This section (Section III) discusses general quality requirements for municipal water supplies, and the methods of treatment for attaining various quality levels. The present quality of particular municipal water supplies in the basin is reviewed.

36. Municipal water use This section (Section IV) is devoted to a detailed breakdown of municipal water use in the Delaware River Service area. There is a discussion of population served, daily usage and per capita water use. These are further subdivided geographically by state and service area. The source of supply is tabulated for ground and surface usage. Private and public ownership of supplies and their relationship to consumption is also discussed.

37. Industrial water quality The quality of industrial water varies with the need of the particular industry. For example, the quality requirements of a steel plant for quench water are lower than those of a food processing plant for water incorporated in the product. Even within an industry varying demands are placed upon the quality of the supply, i.e., cooling waters are of a lower quality than boiler feed waters. These various aspects of quality, methods of treatment and present industrial water quality in the basin are discussed in detail in this section (Section V).

38. Industrial water use This section (Section VI) geographically summarizes industrial water usage by state and service area. Sources of supply in terms of ground or surface water, and in terms of ownership are also discussed. The use of water within given industries is detailed by purpose to allow comparisons within and between industries. Water usage figures on a per employee basis for the industries within the basin have been developed to assist in projecting future industrial water needs.

39. Total municipal and industrial water use Section VII summarizes the municipal and industrial water usage in the basin and the Delaware River Service Area. This treatment is parallel to the development of the municipal and industrial water use sections in the geographical and source analyses.

SECTION III - MUNICIPAL WATER QUALITY

Introduction

40. The municipal water supply system services a diverse clientele with varied quality requirements dependent upon end uses. For domestic use, the water supplies must not only be safe and potable but preferably taste-free, odorless and colorless. The water supply should also be soft and non-corrosive in view of the increased use of water in home laundering, central heating and air conditioning systems.

General Requirements

41. Most surface water sources and many ground water sources require some form of water treatment to meet the sanitary and chemical requirements for a municipal water supply. Such treatment processes as aeration, chemical coagulation, sedimentation, filtration, softening, adjustment of acidity and chlorination are commonly employed. The Drinking Water Standards promulgated by the U.S. Public Health Service specify quality requirements 1/. In general terms, these Standards require that drinking water be:

a. free from disease causing organisms
b. free from toxic substances
c. reasonably soft
d. non-corrosive
e. low in objectionable minerals
f. clear, odorless and tasteless

Treatment Methods

42. <u>Sedimentation</u> In many instances surface waters contain

suspended material as a result of drainage from upland areas. Sedimentation is employed in large lakes, reservoirs or in specially designed settling basins. Removal of suspended material is accomplished by lowering the velocity of the water to a level which allows the suspended particles to settle to the bottom. In the Delaware area, the sediment concentrations of the streams are generally low with higher concentrations following storm runoff.

43. Coagulation The very fine suspended or colloidal material which does not readily settle out in the sedimentation process is subsequently treated by coagulation. This process utilizes chemicals which form a gelatinous precipitate or floc which absorbs the colloidal and finely divided materials and causes them to settle more rapidly.

44. Filtration To produce the clear water demanded by consumers, a finishing process called filtration is used. This is the mechanical screening of the previously treated water through beds of fine sand. This process removes nearly all traces of turbidity and color that may remain after coagulation and sedimentation.

45. Aeration Aeration is utilized in many cases as a method of removing taste and odor from a water supply. Aeration is also used to release the entrained gases such as carbon dioxide. In this process large quantities of air are bubbled through the water, or, as is more common in water treatment, the water is sprayed into the air in a fine spray.

46. Softening Softening removes the carbonate and non-carbonate hardness caused by the calcium and magnesium contained in a water supply in the dissolved state. The addition of lime or lime and soda ash produces a chemical reaction with the hardness forming insoluble compounds which can be removed by sedimentation and filtration.

47. Chlorination The application of gaseous or liquid chlorine, or chlorine containing compounds to water generally for the purpose of disinfection are sometimes used for accomplishing other biological or chemical results such as taste and odor control. The chlorination may take place prior to, during or after any of the above processes and is referred to in such cases as pre or post

chlorination.

Quality of Municipal Surface Supplies in the Delaware River Basin

48. The Delaware River and its tributaries are utilized as a source of raw water by a number of large communities. A review of the treatment facilities of typical communities will give an indication of the comparative quality in various sections of the basin.

49. In the headwaters section of the Delaware, the predominant user is the City of New York. The quality of the water in this area is high enough to warrant a minimal degree of treatment. This consists of sedimentation in the large reservoirs, such as Pepacton, and chlorination, aeration and limited coagulation before delivery to the distribution system in New York City.

50. The section of the River between Port Jervis and Easton serves as a source of raw water for the City of Easton. Treatment consists of coagulation, sedimentation, filtration and chlorination. The water is withdrawn directly from the River and requires the removal of turbidity and pH adjustment for corrosion prevention.

51. From Easton to Trenton the quality of the River water grows progressively poorer due to pollution from municipal and industrial waste effluents and the addition of the flow of the Lehigh River. Treatment at Trenton which uses Delaware River water consists of coagulation, sedimentation, filtration and chlorination. Reduction of color and turbidity as well as taste and odor are important treatment problems.

52. Increasing use of the River water between Trenton and Philadelphia, as well as the tidal nature of the stream in this area, create a build-up in chemical content. All this contributes to the need for the high degree of treatment that the City of Philadelphia utilizes. Besides coagulation, sedimentation,

filtration and chlorination, the treatment of these waters includes the use of chlorine dioxide, and the addition of metaphosphates to reduce hardness, alkalinity, turbidity and color.

53. The Schuylkill River is used for water supply by the cities of Norristown, Pottstown and Philadelphia. Pottstown utilizes coagulation, activated carbon, sedimentation, filtration and chlorination as treatment for its water supply. Norristown in addition uses pre-chlorination while Philadelphia uses metaphosphates in addition to all of these.

54. Brandywine Creek is used as a source of water supply for the City of Wilmington, Del. Treatment for this supply consists of sedimentation, filtration and chlorination.

Summary

55. As the stream is subjected to increasing use and reuse on its journey from the headwaters to the sea, the quality of the stream deteriorates. This debasement of quality necessitates increasingly complex methods of treatment to prepare the water for municipal consumption. Newer technologies require water of even higher quality than that used for human consumption. This in turn has led to the development of more extensive and better methods of treatment. The municipal water supply system of today services domestic, commercial, industrial and other users with these higher requirements of quality.

56. The treatment plant of today is more complex than the reservoir and chlorination practices utilized a half century ago. The choice for municipal water supply today is between long aqueducts from streams in sparsely settled distant upland areas, and large, complex treatment installations from streams in the downstream areas where industrialization and its by-products have taken their toll.

SECTION IV - MUNICIPAL WATER USE

Introduction

57. Municipal water supply involves the gathering, protection, storage, purification and distribution of water for domestic, commercial, industrial and other uses within a water supply system. In the Delaware basin, larger municipalities usually make use of surface or stream sources to secure an adequate supply of water whereas smaller communities, institutions and private utilities are more apt to use underground sources, e.g., wells or springs.

58. The water supply system serving the larger metropolitan areas of New York, Philadelphia, Wilmington and northeastern New Jersey are very complex. They serve many municipalities and unincorporated areas going beyond county lines.

59. Delaware River study area This study area, which includes potential users of Delaware River waters, reaches beyond the actual Delaware River watershed and includes the entire States of New Jersey and Delaware, and the New York City Metropolitan Area, including Long Island and adjacent counties. This area (Figure 1) is referred to as the Delaware River Service Area.

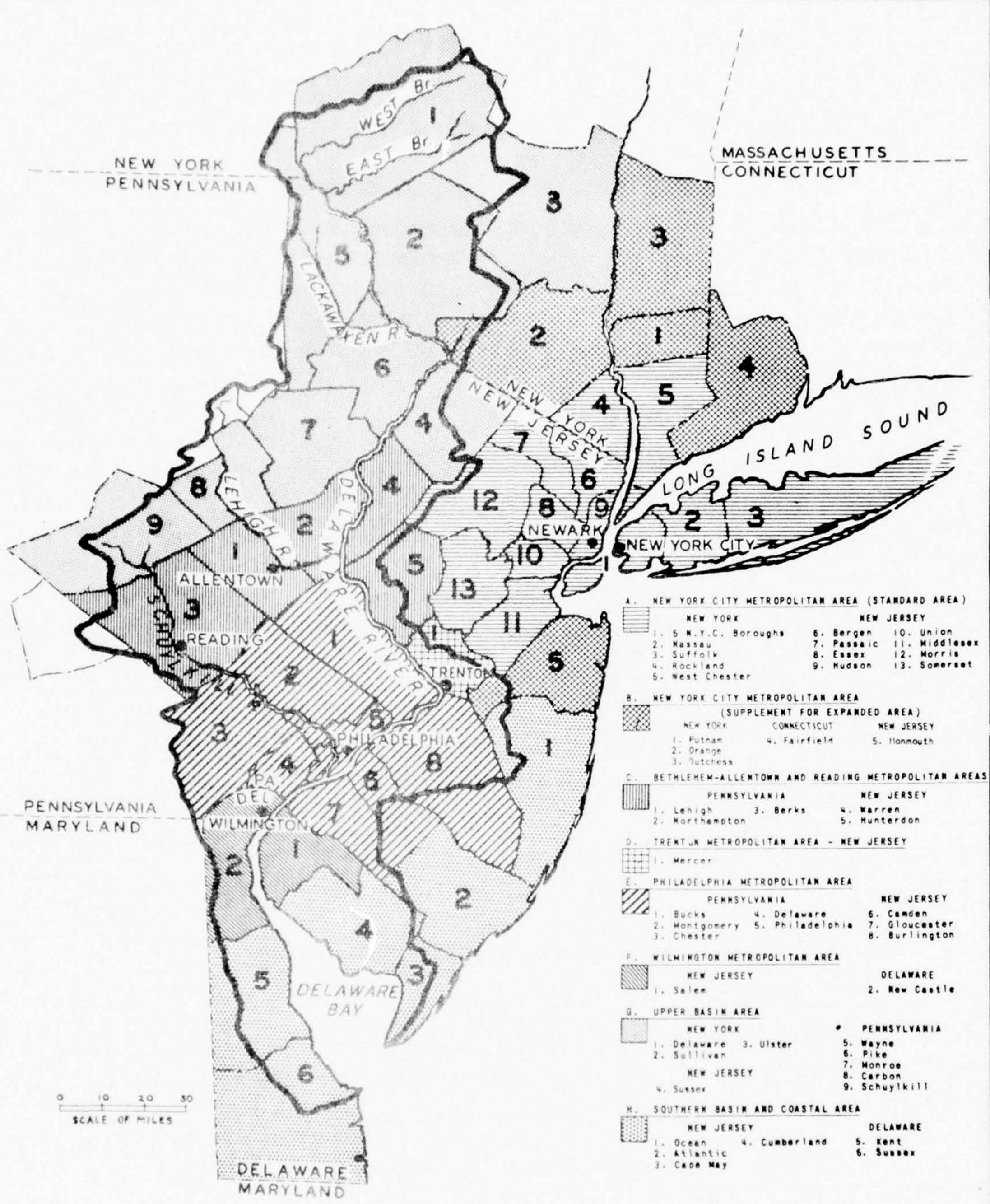
Definitions

The following definitions are used in this report:

60. Municipal Water Use This is the gross municipal use and includes domestic, industrial, public (fire uses and normal leakage) which are supplied by a community water system, whether publicly or privately owned.

61. Domestic Water Use This is defined as that portion of municipal water used for household purposes and by commercial

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART A – MUNICIPAL AND INDUSTRIAL WATER USE

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

FIGURE 1

DELAWARE RIVER BASIN AND SERVICE AREA

establishments such as stores, hotels, restaurants and markets.

62. Industrial Water Use This is the use of water in connection with industrial operations or processes.

63. Public Water Use This is the use of water within the community by public agencies for purposes such as:

Fire Protection
Public Swimming Pools
Parks and Lawns
Leakage
Fountains and Gardens

64. Delaware Service Area This is the area comprising the Delaware River basin together with the counties of the neighboring region which are economically linked to the Delaware or may be dependant upon it in varying degrees for water supply. Figure 1 presents a map of this area, grouping the counties included into eight Sub-regions and depicting the relationship of the basin to the Service Area. The outer border of the map encloses the Delaware Service Area while the heavy line shows the boundary of the Delaware River basin itself which comprises only a portion of the Service Area.

65. In Basin This is the area within the heavy boundary lines of Figure 1 denoted as the Delaware River basin. The term as used in this report and in Tables 1 through 6 which follow later in this section denotes water consumption on the basis of the location of the population consuming this water. Therefore, the in basin term would apply to such cases as the City of Chester, Pa. where the water is diverted from the Susquehanna basin but consumed within the basin. It does not apply to cases such as New York City where the water is diverted from within the basin but consumed outside of the basin.

66. Out of Basin This is the area within the Delaware Service Area as defined above but outside of the Delaware River basin or the shaded area outside the heavy line shown on Figure 1. The use of this term in the report and in Tables 1 through 6 is

based upon the point of consumption of the water and not its source. The use of water from the Delaware River basin by the City of New York and northeastern New Jersey is considered in the out of basin category but is also noted in the footnotes as diversions from the basin.

67. Publicly Owned Municipal Water Supply This refers to all municipal water supplies owned or operated by a municipal, county, or district organization.

68. Privately Owned Municipal Water Supply This refers to all municipal water supplies owned or operated by a private corporation or similar type organization.

69. General water use requirements The demand for water for municipal use varies widely from community to community with per capita water usage gradually increasing over the years. Average per capita water use today in the United States is approximately 140 gallons per day (gpd) for domestic, commercial, industrial, public and other uses. 1/ Important factors which influence water consumption and are responsible for wide variations among communities are size and type of community; proportion of residential, commercial and industrial development; the water pressure maintained; metered or unmetered service; maintenance of the system; economic condition of the community; and the rate charge for water. Typical usage for the average community in the Delaware area on the basis of national experience 1/ might be as follows:

Type of Use	GPD Per Capita	Percent of Total Use
Domestic	60	43
Commercial	26	19
Industrial	35	25
Public and Losses	19	13
Total	140	100

1/ This and the following footnotes refer to respectively numbered entries in the Bibliography at the end of this report.

70. Variation in rate of use There are hourly, daily and seasonal variations in the rates of consumption of water within any municipal system. The amount of variation of water consumption for different periods may be indicated as follows:

a. Year to year - a tendency toward an increase in water use - for air-conditioners, clothes and dishwashers, garbage disposal units and multi-bathroom homes coming into general use with a rising standard of living.
b. Season to season - highest use during the summer, lowest during the winter. Maximum monthly demand is about 120% of the average monthly demand. In resort areas the seasonal pattern is more marked with the influx of vacationers. Here water use may be doubled during the vacation season.
c. Day to day - generally uniform during the week but lowest on weekends. Maximum daily demand is about 165% of the average daily demand.
d. Hour to hour - lowest usage between midnight and early morning with maximum occurring about noon. Maximum hourly demand is about 230% of the average hourly demand.

71. Source of data Data on municipal water use, population served and source of supply were taken from published inventories of municipal water supplies by the United States Public Health Service 2/ 3/ 4/, from the current inventory of all communities serving populations of 100 persons or more (unpublished), and from the records and reports of Federal and state agencies for the 1949-1956 period. These are listed under Selected References in the Bibliography.

Delaware River Service Area

72. Introduction To illustrate the water use in the Delaware River Service Area and basin, six tables have been prepared which indicate the various breakdowns of water use within the Delaware Service Area and its sub-regions. Tables 1 and 4 delineate the populations served by municipal systems in the sub-categories of

TABLE 1

POPULATION SERVED BY MUNICIPAL WATER SUPPLIES
STATE PORTION OF SERVICE AREA+
By Source, Basin Location, and Ownership
Annual Average for 1955
(Thousands)

Source / Basin Location / Ownership	Conn.	Del.	N.J.	N.Y.	Penn.	Total Service Area
			States			
Ground Water	37.7	92.5	2080.7	1767.4	402.5	4380.8
In Basin	0	79.4	595.2	21.9	377.7	1074.2
Public	0	47.4	386.2	7.3	285.8	726.7
Private	0	32.0	209.0	14.6	91.9	347.5
Out of Basin	37.7	13.1	1485.5	1745.5	24.8	3306.6
Public	0	11.2	583.0	584.0	7.0	1524.3
Private	37.7	1.9	562.4	1162.5	17.8	1782.3
Surface Water	423.2	178.9	3284.7	8530.7	3585.5	16003.0
In Basin	0	178.9	246.6	40.3	3524.0	3989.8
Public	0	148.9	226.2	30.3	2870.2	3275.6
Private	0	30.0	— 20.4	10.0	653.8	714.2
Out of Basin	423.2	0	3038.1*	8490.4**	61.5	12013.2
Public	82.4	0	2220.7*	8414.8**	56.5	10774.4
Private	340.8	0	817.4*	75.6	5.0	1238.8
Total						
In Basin	0	258.3	841.8	62.2	3901.7	5064.0
Out of Basin	460.9	13.1	4523.6*	10235.9**	86.3	15319.8
Public	82.4	207.5	3756.2	9035.4	3219.5	16301.0
Private	378.5	63.9	1609.2	1262.7	768.5	4082.8
Grand Total	460.9	271.4	5365.4	10298.1	3988.0	20383.8

+ All figures in Tables 1-6 are based upon the population served by municipal systems and the water withdrawn for delivery to these populations. They do not include withdrawals of water for use in treatment processes in the municipal water plants. These withdrawals are returned directly to the river and do not enter the municipal systems.

* See Table 2 ** See Table 3

TABLE 2

WATER USE BY MUNICIPAL WATER SUPPLIES
STATE PORTION OF SERVICE AREA+
By Source, Basin Location, and Ownership
Annual Average for 1955
(Million Gallons Per Day)

Source Basin Location Ownership	Conn.	Del.	N.J.	N.Y.	Penn.	Total Service Area
Ground Water	5.6	10.3	207.3	123.2	39.6	385.0
In Basin	0	9.3	71.3	2.3	37.9	120.8
Public	0	6.0	52.8	1.0	31.9	91.7
Private	0	3.3	18.5	1.3	6.0	29.1
Out of Basin	5.6	1.0	136.0	119.9	1.7	264.2
Public	0	0.8	85.7	59.2	0.2	145.9
Private	5.6	0.2	50.3	60.7	1.5	118.3
Surface Water	64.5	32.6	407.3	1282.6	525.9	2312.9
In Basin	0	32.6	34.0	6.7	518.7	592.0
Public	0	24.9	31.1	5.4	461.1	522.5
Private	0	7.7	2.9	1.3	57.6	69.5
Out of Basin	64.5	0	373.3*	1275.9**	7.2	1720.9
Public	13.9	0	272.9*	1266.8**	6.5	1560.1
Private	50.6	0	100.4*	9.1	0.7	160.8
Total						
In Basin	0	41.9	105.3	9.0	556.6	712.8
Out of Basin	70.1	1.0	509.3*	1395.8*	8.9	1985.1
Public	13.9	31.7	442.5	1332.4	499.7	2320.2
Private	56.2	11.2	172.1	72.4	65.8	377.7
Grand Total	70.1	42.9	614.6	1404.8	565.5	2697.9

+ See Table 1 ** See Table 3

* Includes an estimated 21,000 persons in Union County, New Jersey served by private supply, and an estimated 19,000 persons in Middlesex County, New Jersey served by public supply by the diversion of 8.2 and 4.2 mgd, respectively, through the Delaware-Raritan Canal.

TABLE 3

PER CAPITA CONSUMPTION BY MUNICIPAL WATER SUPPLIES
STATE PORTION OF SERVICE AREA+
By Source, Basin Location, and Ownership
Annual Average for 1955
(Gallons Per Capita Per Day)

Source / Basin Location / Ownership	Conn.	Del.	N.J.	N.Y.	Penn.	Total Service Area
			States			
Ground Water	149	111	100	69	98	88
In Basin	-	117	120	105	100	112
Public	-	127	137	137	112	126
Private	-	103	89	89	65	84
Out of Basin	149	76	92	69	69	80
Public	-	71	93	102	29	96
Private	149	105	89	52	84	66
Surface Water	152	182	124	150	147	145
In Basin	-	182	138	166	147	148
Public	-	167	137	178	161	160
Private	-	257	142	130	88	97
Out of Basin	152	-	123 *	150 **	117	143
Public	169	-	123 *	151 **	115	145
Private	148	-	123 *	120	140	130
Total						
In Basin	-	162	125	145	143	141
Out of Basin	152	76	113 *	136 **	103	130
Public	169	153	118	147	155	142
Private	148	175	107	57	86	93
Grand Total	152	158	115	136	142	132

+ See Table 1   * See Table 2

**Includes an estimated 2,400,000 persons in New York City served by public supply by the diversion of 350 mgd from the Delaware basin.

TABLE 4

POPULATION SERVED BY MUNICIPAL WATER SUPPLIES
SUB-REGIONS+
By Source, Basin Location, and Ownership
Annual Average for 1955
(Thousands)

Source / Basin Location / Ownership	Sub-Regions A	B	C	D	E	F	G	H
Ground Water	2758.6	195.7	197.3	34.3	636.5	83.7	114.9	359.8
In Basin	8.3	1.0	194.0	6.3	629.5	83.7	70.5	80.9
Public	2.8	1.0	139.2	1.8	457.1	26.6	20.9	77.3
Private	5.5	0	54.8	4.5	172.4	57.1	49.6	3.6
Out of Basin	2750.3	194.7	3.3	28.0	7.0	0	44.4	278.9
Public	1175.5	136.3	0.5	5.8	6.3	0	12.5	187.4
Private	1574.8	58.4	2.8	22.2	0.7	0	31.9	91.5
Surface Water	11146.1	707.7	394.2	168.0	3043.9	183.2	301.3	58.6
In Basin	0	10.6	389.1	168.0	3043.9	183.2	183.2	11.8
Public	0	10.6	353.5	168.0	2482.5	153.2	96.0	11.8
Private	0	0	35.6	0	561.4	30.0	87.2	0
Out of Basin	11146.1*	697.1	5.1	0	0	0	118.1	46.8
Public	10396.9*	218.7	3.8	0	0	0	108.2	46.8
Private	749.2*	478.4	1.3	0	0	0	9.9	0
Total								
In Basin	8.3	11.6	583.1	174.3	3673.4	266.9	253.7	[illegible]
Out of Basin	13896.4*	891.8	8.4	28.0	7.0	0	162.5	325.7
Public	11575.2	366.6	497.0	175.6	2945.9	179.8	237.6	323.3
Private	2329.5	536.8	94.5	26.7	734.5	87.1	[illegible]	95.1
Grand Total	13904.7	903.4	591.5	202.3	3680.4	266.9	416.2	418.4

+ See Table 1

* Includes an estimated 2,400,000 persons in New York City served by public supply by the diversion of 350 mgd from the Delaware basin, and an estimated 21,000 persons in Union County, New Jersey served by private supply, and an estimated 19,000 persons in Middlesex County, New Jersey served by public supply by the diversion of 8.2 and 4.2 mgd, respectively, through the Delaware-Raritan Canal.

TABLE 5

WATER USE BY MUNICIPAL WATER SUPPLIES
SUB-REGIONS+
By Source, Basin Location, and Ownership
Annual Average for 1955
(Million Gallons Per Day)

Source / Basin Location / Ownership	A	B	C	D	E	F	G	H
	Sub-Regions							
Ground Water	214.6	20.2	26.0	3.0	69.8	7.2	8.6	35.6
In Basin	0.4	0.1	25.7	0.5	69.5	7.2	5.8	11.6
Public	0.3	0.1	19.5	0.1	55.2	2.8	2.4	11.3
Private	0.1	0	6.2	0.4	14.3	4.4	3.4	0.3
Out of Basin	214.2	20.1	0.3	2.5	0.3	0	2.8	24.0
Public	113.0	13.0	-	0.6	0.3	0	0.6	18.4
Private	101.2	7.1	0.3	1.9	-	0	2.2	5.6
Surface Water	1604.3	97.0	57.8	26.1	448.9	33.3	37.0	8.5
In Basin	0	2.6	57.1	26.1	448.9	33.3	21.3	2.7
Public	0	2.6	52.1	26.1	402.4	25.6	11.0	2.7
Private	0	0	5.0	0	46.5	7.7	10.3	0
Out of Basin	1604.3*	94.4	0.7	0	0	0	15.7	5.8
Public	1509.1*	30.1	0.4	0	0	0	14.7	5.8
Private	95.2*	64.3	0.3	0	0	0	1.0	0
Total								
In Basin	0.4	2.7	82.8	26.6	518.4	40.5	27.1	14.3
Out of Basin	1818.5*	114.5	1.0	2.5	0.3	0	18.5	29.8
Public	1622.4	45.8	72.0	26.8	457.9	28.4	28.7	38.2
Private	196.5	71.4	11.8	2.3	60.8	12.1	16.9	5.9
Grand Total	1818.9	117.2	83.8	29.1	518.7	40.5	45.6	44.1

+ See Table 1
* See Table 4

TABLE 6

PER CAPITA CONSUMPTION BY MUNICIPAL WATER SUPPLIES
SUB-REGIONS+
By Source, Basin Location, and Ownership
Annual Average for 1955
(Gallons Per Capita Per Day)

Source / Basin Location / Ownership	Sub-Regions A	B	C	D	E	F	G	H
Ground Water	78	103	132	87	110	86	75	99
In Basin	48	100	132	79	110	86	82	143
Public	107	100	140	56	121	105	115	146
Private	18	-	113	89	83	77	69	83
Out of Basin	78	103	91	89	43	-	63	86
Public	96	95	-	103	48	-	48	98
Private	64	122	107	86	-	-	69	61
Surface Water	144	137	147	155	147	182	123	145
In Basin	-	245	147	155	147	182	116	229
Public	-	245	147	155	162	167	115	229
Private	-	-	140	-	83	257	118	-
Out of Basin	144 *	135	137	-	-	-	133	124
Public	145 *	138	105	-	-	-	136	124
Private	127 *	134	231	-	-	-	101	-
Total								
In Basin	48	233	142	153	141	152	107	154
Out of Basin	131 *	128	119	89	43	-	114	91
Public	140	125	145	153	155	158	121	118
Private	84	133	125	86	83	139	95	62
Grand Total	131	130	142	144	141	152	110	110

+ See Table 1
* See Table 4

geographical location, ownership and source of supply (ground or surface). Tables 2 and 5 detail the same categories for actual water use. Tables 3 and 6 present the data for per capita consumption for each of the same categories. These tables and Figure 2 present the data within the Delaware River Service Area for 1955.

73. Service Area The total population served by the municipal water supply systems in the United States in 1955 was 115 million persons. This represented a total municipal water consumption, including those industries served by municipal water systems, of 16.1 billion gpd, or the equivalent of 140 gallons per day. 1/ From Tables 1, 2 and 3, the corresponding figures for the Delaware River Service Area are 20.4 million persons served a total of 2.70 billion gpd, or a per capita consumption of 132 gpd. This would indicate that the Service Area contains 18% of the national population served by municipal water supply systems and consumes 17% of the total municipal water consumption of the country, yet represents less than 1% of the geographic area of the United States. The per capita consumption for the area is 94% of the figure of the country as a whole.

74. Ownership data for the nation as a whole are available only for municipal water supplies serving populations of 25,000 or more. 1/ On the basis of these data, approximately 80% of the national population connected to municipal systems is served by publicly owned supplies. Publicly owned supplies serve more than 16.3 million of the total population in the Service Area, with 2.3 billion gpd. This represents 80% of the population connected and 86% of the water use, or the same as the national average.

75. Data for sources of supply are also available only for municipal water supplies serving populations of 25,000 or more. Nationally, approximately 75% of the population served by municipal supplies utilize surface sources, whereas in the Service Area 79% or 16 million people use surface sources.

76. The pattern of municipal water in the Service Area is similar to the national pattern as shown in the foregoing paragraphs. It is interesting to note that the

population serviced by municipal water supply systems in the Service Area represent approximately 95% of the total population of the area, whereas the national average is about 70%. This may be attributed to the higher degree of urbanization of the Service Area as compared to the nation as a whole.

77. In and Out of Basin Twenty-four percent of the population served within the Service Area live within the basin. The volume of water used by this population represents 26% of the total. This is a per capita consumption 10% higher than in that portion of the Service Area outside the basin.

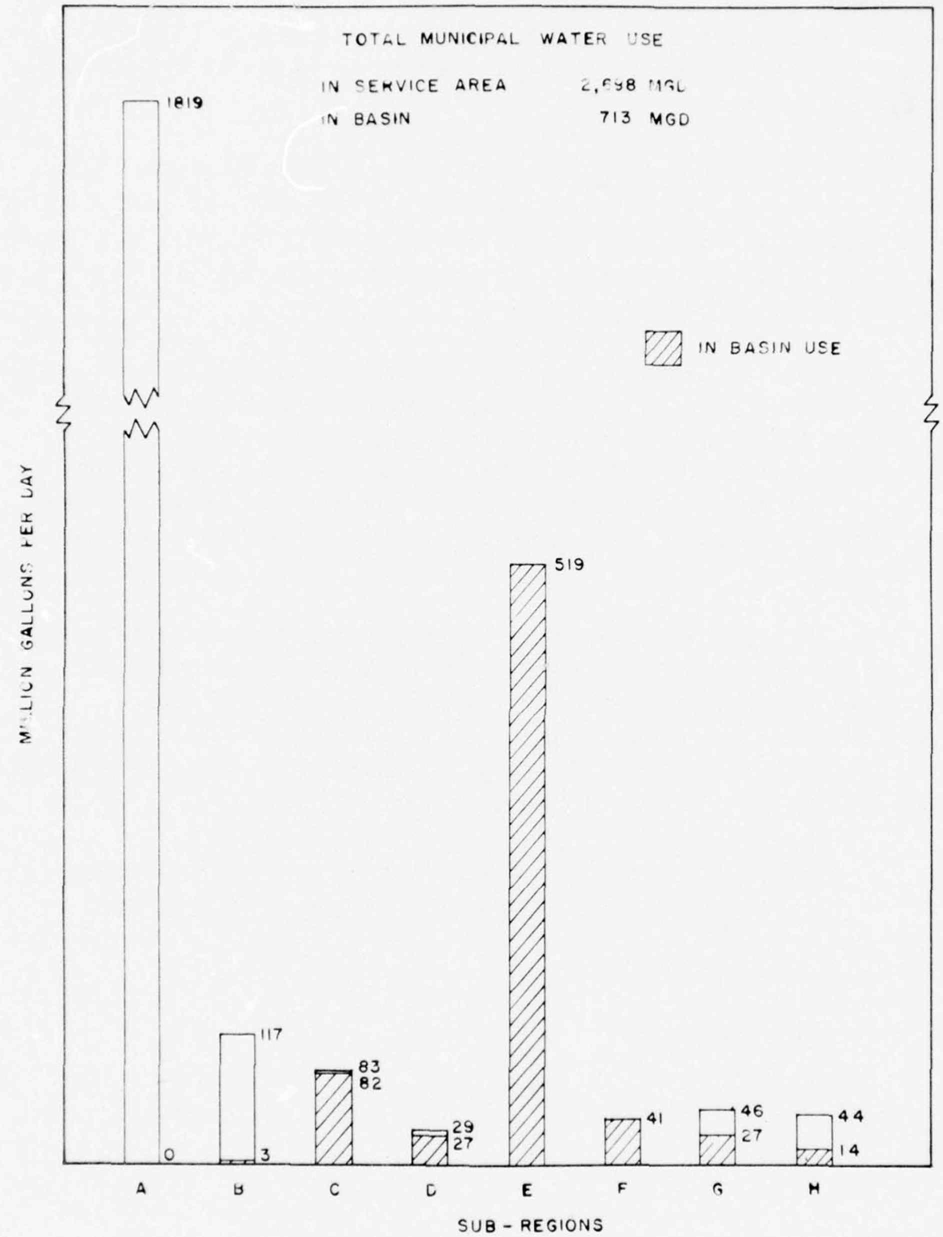
78. The population served by ground waters within the basin and in the Service Area adjacent thereto each represent 22% of the total in each area. The privately owned water supplies service one-fifth of the population within the basin and one-fifth in the area adjacent to the basin. These figures include the New York City and northern New Jersey supplies presently diverted from basin waters as out of basin areas. This is explained in the footnotes to Tables 1 - 6.

79. States The following table showing the percentage of the population served and the percentage of water use, demonstrates that New York is the major user of water in the Service Area. Table 2 shows that New York utilizes only 33% of the waters used from the basin when the New York City diversion of 350 mgd (for 1955) is added to the basin total of about 700 mgd.

State Portion of Service Area	Percentage of Population Served	Percentage of Water Use
Connecticut	2	3
Delaware	1	2
New Jersey	26	22
New York	51	52
Pennsylvania	20	21
Total	100%	100%

80. Per capita consumption varies between the states from a low of 115 gpd in New Jersey to a high of 158 gpd in Delaware.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART A
MUNICIPAL AND INDUSTRIAL WATER USE
U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

FIGURE 2
AVERAGE ANNUAL MUNICIPAL WATER USE
DELAWARE RIVER BASIN AND SERVICE AREA
1955

81. Ground water use is highest in the State of New Jersey where approximately 40% of the population is serviced. Delaware ranks second with 34% and New York, Pennsylvania and Connecticut follow with 17%, 10% and 8% respectively.

82. Public and private ownership of municipal supplies within the five states follows the general pattern for the Service Area as a whole, with the exception of Fairfield County, Connecticut where private ownership is more prevalent, accounting for more than 80% of the County's total.

83. Sub-regions Tables 4, 5 and 6 describe the classification of water use within the individual Sub-regions as delineated by the Corps of Engineers and shown on Figure 1. The population serviced by municipal systems is greatest in Sub-region A (New York City Metropolitan area). The Philadelphia complex covered in Sub-region E (Philadelphia Metropolitan area) is the second largest, and the smallest Sub-region is represented by Sub-region D (Trenton Metropolitan area). Sub-region H (Southern Basin and Coastal area) shows the largest percentage of ground water use, whereas Sub-region A has the largest preponderance of surface water use.

84. Water consumption is essentially of the same order of magnitude. The per capita consumption figures for the individual areas show little variation, with a high of 152 and a low of 110 gpd. In viewing the smaller sub-units of Table 6, a greater variation is evident. For example, privately owned supplies exhibit a lower per capita use than publicly owned supplies. Also ground supplies are generally lower in per capita use than surface supplies.

Summary

85. Surface water supplies predominate both in the basin and in the adjacent Service Area. Public ownership is more predominant than private ownership both within the basin and in the adjacent area. Per capita usages vary considerably throughout the Service Area. With more than 20 million people served by municipal systems in the

Service Area, the water use of more than 2.5 billion gpd gives a per capita consumption of approximately 132 gpd. The per capita water use within the basin averages approximately the same as in the Service Area adjacent to the basin. The category with the highest per capita usage is the in basin, publicly owned, surface supplies; the one showing the lowest per capita usage is privately owned, out of basin, ground water supplies. Generally, the more populated and more highly industrialized areas show the higher usage and per capita consumption. This is to be expected with increased use of water by the greater number of commercial and industrial establishments in the larger communities.

SECTION V - INDUSTRIAL WATER QUALITY

Quality Requirements

86. General The industrial processes in which water is used are so numerous and varied, that the standard of quality required for such supplies necessarily covers a wide range. For example, process water used in many food industries conforms with standards as strict as, and in many respects, more stringent than, those required for municipal supply. On the other hand, cooling water need not be of such high quality.

87. Cooling The largest single use of water by industry is for cooling purposes. The volume and temperature of the water are of the greatest importance. The cold, uniform temperature of underground waters makes it most desirable for cooling purposes, but this source of water has definite limitations, particularly where large volumes are needed. It becomes necessary, therefore, to utilize surface water to a greater extent; cooling towers and other facilities are often used. Almost any source of water, including sea water, can be used for cooling purposes. Many industries requiring large amounts of cooling water have established plants on tidewater sites to take advantage of the available supply. Some cooling equipment is especially designed for the use of brackish waters.

88. Cooling - Requirements In addition to the temperature and volume requirements discussed above, cooling water should not be unduly corrosive and should not cause excessive deposition of scale. Oil or other organic matter and slime forming organisms in water affect its utility for cooling purposes. Water polluted by sewage or organic industrial effluents may lead to the growth in cooling condensers of gelatinous masses of micro-organisms which reduce the efficiency of the cooling. Chlorine is used as a treatment to prevent these growths. Suspended solids are also objectionable when they lodge on heat exchanger surfaces and, with slime and organic deposition, cause loss in cooling efficiency and accelerate corrosion. The requirements in oil refineries and steel mills are the same. In these industries the primary use is steam production and cooling.

However, in the rolling of steel, a chloride content above 150 parts per million (ppm) in the cooling water causes a rapid deterioration of the rolls.

89. Process - General Process waters require many standards of quality, depending upon the specific requirements of the manufacturing process and the quality of the product. Most industries prefer to use soft water instead of hard water. Hard water is unsuitable for processes such as bleaching of textiles, canning of peas, manufacture of soap, electroplating, processing of milk, degreasing of wool and tanning. For a large number of industrial processes, it is important for water to be free of iron; for example, bleaching, tanning and many dyeing processes. With few exceptions, water used for industrial purposes should not contain excessive amounts of organic matter, and should be relatively free of bacteria. It is desirable to have a source of water which varies little in character; if this is impossible, the extent of variation should be known. Arrangements can then be made for forecasting these changes or for detecting them quickly, and if possible, for neutralizing their effects. Characteristics that are objectionable for one process may not be objectionable for another.

90. Process Requirements - Paper Industry In the paper making industry, the quality of the water is important. Paper mills making newsprint and boxboard may use untreated water if it is properly screend or settled to remove grit and large particles. For high grade paper, however, process water must meet more stringent requirements. It should not be hard, since calcium and magnesium cause difficulty in applying size; it should not contain iron and manganese which cause discoloration of pulp and paper; it should be colorless and free from suspended matter; it should not contain an excessive amount of carbon dioxide; it should be substantially neutral in reaction; and it should be as free as possible of organic matter and bacteria. Traces of oils or fats are objectionable in all cases, since each speck forms a semi-transparent spot in the finished paper.

91. Process Requirements - Textile Industry In the textile industry the most important requirements are the absence of color, turbidity and suspended matter, and limitations on the hardness,

manganese and iron content. Water quality requirements of process waters reported for some industries are given in Table 7.

92. Process Requirements - Food Industry For all food and beverage products, the water used must meet the standards for safe drinking water. An overall standard of water quality for the food industry is not a workable one. Table 8 shows the specifications of treated water for various food industries. A low hardness is important in some food industries such as canning of peas, since it affects their tenderness, and the manufacture of ice and some carbonated beverages, since it causes the precipitation of solids. Ice manufacture also requires a low mineral content.

93. Boiler feed The quality tolerances vary for boilers operated at different pressures, with exacting requirements for high pressure boilers. A water suitable for boiler feed is one which will not deposit any scale-forming substances, is not corrosive and will result in neither priming nor foaming. Waters meeting the specifications for boiler feed are seldom obtainable without artificial purification. Various methods of treatment are used, including softening, demineralization and deaeration.

Treatment

94. Methods Experience has established definite specifications for water requirements in most industries and has indicated tolerances beyond which satisfactory performance is not obtainable. Some degree of treatment is generally required to meet these specifications. The principles of treatment of water for municipal water supplies apply equally well to process waters; there are some treatment processes that are specifically suited to particular industrial needs. The preparations of boiler feed water and cooling water are examples. Industries in the Delaware basin treat river water in many ways, depending upon the physical location of the plant and the intended use of the water. Filtration of water through sand is used to remove small amounts of turbidity. If the water contains considerable turbidity, settling precedes filtration. Floc-forming chemicals are added for the purpose of enmeshing or combining with

TABLE 7

MAXIMUM TOLERABLE CONCENTRATIONS OF VARIOUS CONSTITUENTS IN INDUSTRIAL PROCESS WATER 5/

Parts Per Million

	High Grade Paper	Low Grade Paper	Textile Dyeing	Tanning
Turbidity	10	100	0.3-25	20
Color	5	25	5-70	10-100
Total Solids	200	500	200	--
Total Hardness ($CaCO_3$)	100	200	0.50	50-500
Iron (Fe)	0.1	1.0	0.1-1.0	0.1-2.0
Manganese	0.05	0.5	0.05-1.0	0.1-0.2

TABLE 8

MAXIMUM TOLERABLE CONCENTRATIONS OF VARIOUS CONSTITUENTS IN WATER USED IN FOOD INDUSTRIES 6/
Parts Per Million

	Washing of Butter	Carbonated Beverages	Manufacture of Ice	Canning	Washing Equipment
Turbidity	1	1	1	1	1
Color (A.P.H.A. units*)	5	10	5	-	20
Taste and Odor	0	0	0	0	0
Iron and Manganese	0.2	0.3	0.2	0.2	0.2
Chlorides (as Cl)	250	250	-	-	-
Total Dissolved Solids	850	850	170-350	-	850
Organic Matter	0	0	-	-	0
Fluorine	1	1	1	1	1

* parts per million of platinum equivalent

settleable and non-settleable, suspended and colloidal matter, resulting in a readily settling precipitate. The floc that has not been removed by sedimentation is generally removed by filtration. The most common coagulants used are aluminum and iron salts. Color, bacteria and other potentially harmful organisms are also removed in this process.

95. Softening Excessive amounts of scale-forming compounds, chiefly the soluble bicarbonates, chlorides and sulfates of calcium and magnesium are removed by various softening processes:

a. The addition of lime and soda ash precipitates calcium as a carbonate and magnesium as a hydrate.
b. The passage of water through a bed of sodium zeolite exchanges sodium for calcium and magnesium ions. The zeolite is regenerated with brine.
c. Demineralization removes dissolved minerals. This involves the use of cation and anion exchange media functioning similarly to sodium zeolite.
d. The addition of phosphate salts in the treatment of boiler feed water precipitates the calcium and magnesium producing a water of very low hardness.

96. The lime process of softening is also effective in removing iron and manganese from water. In some instances, in which waters require treatment solely for the removal of iron and manganese, simple measures such as aeration, with or without sedimentation, followed by filtration prove effective. But often, more complicated treatment, including the use of chemicals, is required.

97. Taste and Odor The correction of taste and odor in water is often accomplished by the treatment processes serving other purposes such as lime softening, coagulation, filtration or aeration. Filtration through granular carbon or treatment with powdered activated carbon is a specific method used effectively for the removal of taste and odor. Chlorine is added to prevent the growth of taste causing slime organisms in the water distribution system.

98. Oxygen removal Oxygen is removed from boiler feed

water by deaeration or chemical treatment. Deaeration is accomplished by boiling or atomizing the water at elevated temperatures. The addition of sodium sulfite is a common chemical means of removing oxygen.

99. Boiler feed water Internal treatment of boiler feed water includes addition of sequestering or surface active agents to prevent the deposition of scale. These include polyphosphates, tannins, starches and lignins. Boiler feed water is often softened by the hot lime soda or hot phosphate method rather than the cold method.

Quality in Basin

100. General The surface water in the Delaware basin is the principal source of water for many industrial and municipal water supplies. Both industries and municipalities use it for the disposal of their wastes. The quality of the water is important since industry frequently requires water of a special quality for its spcific needs. Industry selects the treatment methods that will most effectively and efficiently produce the quality of the water required. If industry is to flourish in the area, water must be available in sufficient quantity and of suitable quality to meet industry's needs.

101. Pollution The quality of the water throughout the basin is generally favorable for most industrial uses. However, pollution of some areas has been a serious problem. Industries which must use a surface supply for industrial purposes have on occasion required additional water treatment and maintenance of equipment because of pollution. Municipal and industrial waste discharges in the lower section of the Delaware River have, in the past, threatened the sanitary quality of the waters in this region. Coal culm and silt have been a serious problem in the Schuylkill River. The removal of silt from the upper Schuylkill in the Schuylkill Restoration Project has notably reduced the amount of coal silt which reaches the Delaware.

102. Hardness Degrees of hardness might be divided into four groups: waters with hardness below 50 ppm may be considered soft; those

with hardness from 50 to 100 ppm are moderately hard; the third group in the range from 100 to 150 ppm are considered hard; and those over 150 ppm are very hard. On this basis the Delaware River in the upper tidal area may be considered as being a soft water. Its mineral content, compared to sources of water supply throughout the country, is about average. It is probable that about 50% of the industries can utilize water having such a mineral content. The water of the Schuylkill River, on the other hand, might be classified as hard. Its total mineral content is higher than that of the water of the Delaware River in the upper tidal area. It is therefore evident that more extensive treatment is required of Schuylkill River water before it can be utilized by many industries.

103. Temperature Water temperature is an important element in natural waters used for cooling purposes. The temperature of the water in the basin is characterized by a seasonal variation; maximum temperatures are reached in July and August, and minimums in January and February. During the eight year period ending December, 1952, the maximum temperature observed at Trenton was 88°F., recorded in July, 1949; the minimum of 32°F., recorded in January, 1952. The temperature recorded at Trenton is generally within 2°F. of the water temperature measured downstream at Marcus Hook.

104. Salinity The lower Delaware River and Bay, and tidal portions of the tributaries in this area are brackish. There is a marked increase in salinity in the main stream and tributaries during dry periods. Little or no surface water is used as a source of industrial water supply in the central and sourthern part of the State of Delaware. By far, the greatest part of the surface water used in the northern part of the State is brackish. Brackish water from the tidal streams in the eastern part of the area accounts for a major portion of the total surface water use in this State. It may be classified as a one purpose water use, since it is used almost exclusively for cooling by industry.

105. Salinity - treatment problems Industries downstream from Eddystone are put to additional cost for water during periods of high chlorides in the River. Increased salinity makes the use of the River water for process manufacturing and boiler feed difficult. Sodium salts in boiler feed water cause foaming, requiring more

frequent blow-down. High chlorides cause excessive corrosion and deterioration of equipment. A high concentration of salt in the River water increases the amount of chemicals needed to soften the water. Methods which have been used by industries to acquire water free of objectionable chlorides during periods of salinity invasions include the purchase of water from nearby municipal supplies, pumping to storage when the chlorides of the River are low or pumping to storage during low tide.

106. A large portion of the fresh water in the State of Delaware is influenced by swamps, being highly colored and low in oxygen, and not too desirable for many important usages. The major part of the fresh water used by industry is derived from the Christina River and its Brandywine and White Clay Creek tributaries. Like the brackish water, much of this water is used for cooling. However, it is also used for many other industrial purposes.

Summary

107. Quality Requirements Water is vital to many industrial processes. Industry requires water of differing qualities, dependent upon the process or use. Process water needs are of a generally higher quality, for industries such as food processing, fine paper making and the manufacture of analytical chemicals. Lower qualities can be utilized in such industries as steel making and coke manufacture.

108. Cooling waters The largest industrial use of water in the basin is for cooling water. The quality of cooling waters is measured generally in terms of its temperature and corrosive effects. Large quantities of brackish or saline waters are used for cooling purposes in the lower basin. These waters are normally corrosive and rather than use treatment to remove the corrosive elements, special non-corrosive equipment is used.

109. Process and boiler waters Treatment of process and boiler waters to meet quality needs is widespread in industry. This is due to the importance of water quality in the quality of the

finished product. Treatment varies in the basin according to needs and available quality. The quality in the basin has also been previously discussed in the Municipal Water Quality Section (Section III).

SECTION VI - INDUSTRIAL WATER USE

Introduction

110. General Industrial water is that water used within an industry for processing, cooling, boiler feed, sanitary and other purposes directly or indirectly related to the production of a product or necessary to the rendering of a service. The industry obtains this water from ground or surface supplies either by purchase from an existing municipal supply or by developing its own supply for its own use. This section of the report includes all industrial water usage whether municipally supplied or self-supplied, using 20,000 gallons or more of water per day, within the Delaware River basin only.

111. Sources of Data The development of detailed water use figures for the industries within the basin was necessary to determine the geographic and volumetric pattern of industrial water use. The data on water use by industries were obtained from a number of sources. Surveys of water use surveys made by the South Jersey Port Commission in 1952 of large New Jersey industries located in the lower Delaware basin, by the consulting firm of Tippetts-Abbett-McCarthy-Stratton in 1954 of industries throughout New Jersey, by a survey made by INCODEL in 1951 on the use of industrial water in the portion of the Delaware River extending from Trenton to Wilmington, were the primary sources of the basin industries in New Jersey. Approximately an 83% sampling of the industrial water use in New Jersey was obtained in this manner. The water use data for the Pennsylvania section of the Delaware basin was obtained from the INCODEL survey and from questionnares sent to all productive enterprises in that State in 1955 by the Pennsylvania Department of Internal Affairs. Water use in Delaware was obtained from inventories made by the U.S. Geological Survey in cooperation with the State geologist, for the entire State in 1953 and for northern Delaware in 1955. An inventory of industries in New York State by INCODEL in 1951 furnished information on water use in that section of the basin. All of the sources were reviewed and the data were updated to the year 1955 where it was necessary by use of employment and production figures.

112. Methodology The water use of industries not surveyed was calculated from employment data of those industries listed in the 1955 Industrial Directories for New Jersey and Pennsylvania and the estimated water use per employee for the various types of industries. The water use per employee was estimated from the per employee use of similar industries in the basin, national averages, and other factors.

113. A comparison of the quantity of water withdrawn by industries is presented by Sub-regions and by state. Only that portion of each Sub-region is considered which lies within the Delaware River basin. These data were analyzed for the following:

a. geographical distribution by water use
b. distribution by types of industries
c. variations within a given industry
d. proportion of use for various industrial purposes.

114. Restrictions Some of the data from the above sources were obtained on a confidential basis. It was agreed that these data would not be released in summaries of less than three industries in order to prevent the identification of individual plants with their respective water use. All of the above sources were utilized in combination with other available materials to develop the industrial water use in the Delaware River basin. In contrast to the municipal water use section which analyzed both the Delaware River basin and the Service Area, the industrial water usage is restricted to the basin alone.

115. Water use within industry There are essentially four purposes for which industry uses water: process water (i.e., water used in contact with the manufacture of a product); cooling; boiler water; and sanitation (service water including clean up). In a country-wide survey of industries in 1950 by the National Association of Manufacturers and the Conservation Foundation, 1/ it was found that among the larger water users cooling is the most important of the several purposes. Fifty-four percent of the water intake was used for this purpose. The most common use is for process water. The pattern of purposes for which water is used in a particular area depends greatly on the types of industries present.

116. Water use within industry - South Jersey Port Commission Study The industries surveyed by the South Jersey Port Commission gave a breakdown of the use of water within their plant into each of the above four categories. Twenty-eight plants, or 32% of the industries, responded to this question. On the basis of their replies the water is used as follows:

	Excluding Steam-electric Plants	Including Steam-electric Plants
Process water	22%	12%
Cooling water	72%	85%
Boiler water	4%	2%
Sanitary and service	2%	1%

117. Water use within industry - INCODEL Study From a survey by INCODEL in 1951 on the use of industrial water from Trenton to Wilmington, it was found that 1% of the water used was for sanitary purposes, 7% for process water, 1% for boiler and 91% for cooling water. The large use for cooling is due to the large number of electrical generating stations and the many oil refineries along the River in this area.

118. Volumetric variations in water use by industry The industries in New Jersey surveyed by the South Jersey Port Commission were requested to give maximum and minimum daily water use during 1952. Twenty-five plants, or 28% of the industries, responded to this question. On the basis of these replies the average minimum daily withdrawal was about 9% below the average daily withdrawal and the maximum was 11% above. This range of daily withdrawals does not mean that the total removal of water for industrial purposes varied to the extent indicated, since the maximum or minimum usage of water by all these plants did not necessarily occur on the same day.

119. Seasonal variations A survey by INCODEL in 1951 found the following seasonal variations of water use for industries located along the Delaware River between Trenton and Wilmington:

Average use, mgd	3,270
Used during summer months, mgd	3,437

Used during winter months, mgd 3,106

About 5% more water was used during the summer months than the yearly average. During the summer period when the flow of water in the Delaware River is decreased, the water requirements of industry appear to be slightly higher. The summer water usage of some of these industries was, however, increased to a much greater extent than indicated above, while a few industries used more water during the winter months.

Water Use

120. Basin totals The total industrial water use in the Delaware River basin is more than two billion gallons per day, including 160 mgd of brackish water (Table 9). This does not include the waters used in the small industries consuming less than 20,000 gpd. This is estimated to be 5% of the total water use or an additional 100 mgd. Nor does this total include the waters used for cooling in the steam electric generation plants located in the basin. Figures on this use are included in the discussion of total water use in Section VII.

121. Little less than 10% of the total water use of two billion gallons per day is obtained from ground water sources (Figure 3). Similarly, less than 10% of this total is obtained from municipal systems. The total industrial water use compares with the total municipal water use of seven hundred million gallons per day in the basin.

122. Industry totals The important water consuming industries are listed in Table 10. The largest industrial user is the primary metals industry with 564 mgd or 27% of the total industrial water use. The second largest user in the basin is the chemical and allied products industry using 421 mgd. The third largest industrial use of water is the petroleum and coal products industry using 397 mgd. These three industries account for 66% or two-thirds of the total industrial water use in the basin. The food products and anthracite mining industry each use more than 100 mgd each.

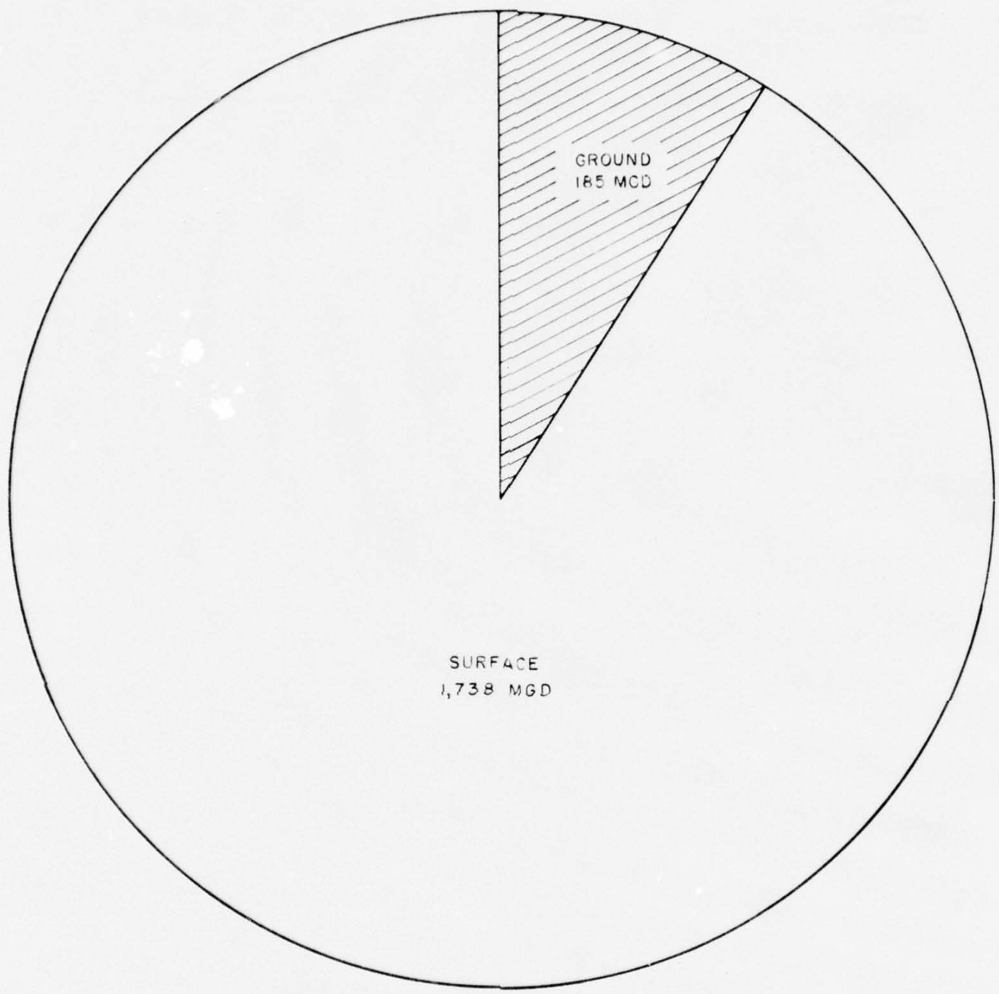
TABLE 9

INDUSTRIAL WATER USE IN DELAWARE RIVER BASIN BY STATES*
Annual Average for 1955
(Million Gallons per Day)

	State				
	Del.	N.J.	N.Y.	Penn.	Total
Municipally Supplied					
Ground	-	18	-	7	25
Surface	17	19	-	115	151
Self-Supplied					
Ground	17	70	-	98	185
Surface	108+	338++	1	1,291	1,738+++
Total Industrial Water Use					
Ground	17	88	-	105	210
Surface	125+	357++	1	1,406	1,889+++
Total	142+	445++	1	1,511	2,099+++

\+ Includes 72 mgd brackish water used in Delaware.
++ Includes 88 mgd brackish water used in New Jersey.
+++ Includes 160 mgd brackish water.
* This does not include the estimated 400 mgd of brackish water used by the Tidewater Oil Company which began operation early in 1956.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



TOTAL AVERAGE ANNUAL SELF-SUPPLIED WATER USE IN THE DELAWARE RIVER BASIN 1,923 MGD

PART A MUNICIPAL AND INDUSTRIAL WATER USE U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE	FIGURE 3 AVERAGE ANNUAL SELF - SUPPLIED INDUSTRIAL WATER USE BY SOURCE DELAWARE RIVER BASIN 1955

TABLE 10

INDUSTRIAL WATER USE BY VARIOUS TYPES OF INDUSTRIES*
Annual Average for 1955
(Million Gallons per Day)

Class		Del.	N.J.	N.Y.	Penn.	Total
				Water Use		
11	Anthracite Mining	-	-	-	107	107
14	Mining-Non-metallics	-	12	-	29	41
20	Food and Kindred Products	-	34	1	71	106
22	Textile Mill Products	9	7	-	26	42
24	Lumber and Wood Products	-	4	-	2	6
26	Paper and Allied Products	4	40	-	49	93
28	Chemicals and Allied Products	65	189	-	167	421
29	Products of Petroleum and Coal	17	61	-	319	397
30	Rubber Products	-	6	-	7	13
31	Leather and Leather Products	-	2	-	4	6
32	Stone, Clay and Glass Products	-	15	-	82	97
33	Primary Metals	-	18	-	546	564
34	Fabricated Metal Products	22	6	-	10	38
35	Machinery (Except Electrical)	-	25	-	36	61
36	Electrical Equipment	-	4	-	10	14
37	Transportation Equipment	-	6	-	29	35
-	Other or Unassignable	25	16	-	17	58
	Total	142	445	1	1,511	2,099

* See Footnote * Table 9

Industrial Water Use Per Employee

123. Introduction In considering the magnitude of industrial water supplies, it is of interest to estimate the water consumption by specific industries. Several methods can be used to do this, such as in terms of units of production, per dollar value added or per employee. For this report, estimates of the water consumption on a per employee basis were prepared for each of the major industries selected. Data were not available to investigate the other methods at the time of writing. The results are shown in Table 11. A column showing the number of plants on which the results are based is included, since the accuracy of averages depends upon the number of cases, and generally small samples are less reliable.

124. Major water users The total water intake for the industries examined averaged 5,300 gallons per employee engaged in manufacturing. The ratio varied greatly among different industries. The highest ratio shown was for anthracite mining which had a water intake of approximately 46,000 gallons per employee. Other high ratios were: about 40,000 gallons per employee for the sand and gravel industry; 17,650 for the cement industry; 14,000 for the petroleum and coal products industry; 13,000 for ice manufacturing; 11,000 for blast furnaces and steel works; 7,900 for chemical manufacturing; 7,300 for pulp, paper and paper-board making; and 4,150 for malt liquor production.

125. Among the larger water users, in Table 11, coal mining, sand and gravel and cement manufacturing use the major part of their requirements for processing purposes. An exceptionally large volume of water is required for washing and preparing coal; almost all of which is returned to the stream. In some cases the water used for this purpose is obtained from the mines. In cement manufacturing large volumes of water are required for washing and preparing the raw materials which are used in the preparation of cement. Water is used extensively for classification (separation by flotation and other means) of minerals and ores. The amount of water used may vary to some extent depending on whether the wet or dry process is used in the final preparation of the cement.

TABLE 11

INDUSTRIAL WATER USE IN DELAWARE BASIN PER EMPLOYEE*

Average use for 1955

Industrial Classification	Type of Industry	Average Use Per Employee Gal/Day	Number of Plants
11	Anthracite Mining	45,900	23
14	Mining of Non-metallic Minerals	21,950	18
144	Sand and Gravel	40,100	11
20	Food and Kindred Products	2,730	86
201	Meat Products	1,320	12
202	Dairy Products	1,750	26
203	Canning and Preserving	1,320	13
2081	Bottled Soft Drinks	1,550	8
2082	Malt Liquors	4,150	8
2097	Manufactured Ice	13,110	8
22	Textile Mill Products	1,680	56
221	Scouring and Combing Plant	1,810	6
226	Dyeing and Finishing Textiles	2,470	18
23	Apparel	420	4
26	Paper and Allied Products	5,820	30
261	Pulp, Paper and Paperboard	7,320	19
27	Printing and Publishing	100	4
28	Chemicals and Allied Products	7,880	88
281	Industrial Inorganic Chemicals	7,020	6
282	Industrial Organic Chemicals	7,330	21
29	Products of Petroleum and Coal	14,120	8
291	Products of Petroleum	13,920	4
293	Coke and By-products	18,570	3
30	Rubber Products	850	12
31	Leather and Leather Products	2,080	10
32	Stone, Clay and Glass Products	6,700	33
324	Cement	17,650	12
33	Primary Metals	7,720	37
331	Blast Furnaces and Steel Works	11,120	20
332	Iron and Steel Foundries	610	10
34	Fabricated Metal Products	830	27
35	Machinery (Except Electrical)	1,890	18
36	Electrical Equipment	360	23
37	Transportation Equipment	400	10

* These figures cover only those plants which were surveyed and using at least 20,000 gpd.

126. Petroleum In petroleum refining, on the other hand, cooling water makes up nearly the entire volume of water used. Except for temperature rise and occasional oil contamination, the water is essentially unchanged upon discharge to the stream. The use of cooling towers and recirculating cooling systems in some plants materially reduce the volume of water needed. Relatively small volumes of water are required in the processing and washing operations.

127. Primary metals The principle use of water in a steel mill is for cooling. There are many such applications in addition to condenser cooling in the powerhouse. Water is used primarily for cooling the equipment pertaining to the manufacture and fabrication of iron and its alloys. Lesser quantities are used for quenching coke, condensing distillates, scrubbing gases, washing down Cottrell precipitation dusts and in tanks for pickling, washing and rinsing sheet metal.

128. Chemicals In the chemical industry the uses of water vary widely. Each individual process requires the use of water in a number of different ways and the processes vary widely from one another in their volume of use. Use of water as a condenser coolant, however, ranks first in volume. Separation and purification of products are frequently affected by distillation and condensation of these materials; large volumes of water are needed for this purpose.

129. Miscellaneous The lowest ratios shown were for the printing and publishing industry, amounting to about 100 gallons per employee; the tobacco industry, amounting to only 115 gallons; and the bakery industry, amounting to 210 gallons.

130. Variations within industry There were considerable ranges in the water requirements within each industry. These variations undoubtedly reflect the diversity of installation and processes, and their relative efficiency in the use of water in plants manufacturing the same type of product. For instance, plants manufacturing their own power would have greater water requirements than plants buying power. If a manufacturer had an inadequate supply he could often reclaim and reuse much of his process water. Cooling water can often be reclaimed by the use of cooling towers. The

quality of the available water often affects the quantity used. If extensive treatment of the raw water is required, it may be more economical to reclaim and reuse waste water from the plant.

131. In the dairy products industry, for example, a wide range was found in the quantity of water used per employee. On the basis of 26 plants reporting values ranged from 236 gallons to 34,000 gallons per employee per day. Eighteen plants reported the quantity of water used in dyeing and finishing textiles varied from 177 to 8,152 gallons per employee per day. For 19 plants reporting the manufacture of pulp, paper and paper-board, the values ranged from 261 to 28,800, while 20 plants, including blast furnaces, steel works and rolling mills, ranged from 607 to 50,600. The 18 plants manufacturing machinery ranged from 76 to 9,100 and 11 plants processing sand and gravel ranged from 4,000 to 106,700 gallons per employee per day.

132. In some instances the values exhibited a relatively narrower range. Values of eight plants reporting the manufacture of ice ranged from 3,125 to 21,600 gallons. For six plants scouring and combing textiles the values ranged from 807 to 2,980 gallons, while four plants manufacturing apparel ranged from 137 to 589. Four petroleum refining plants showed a range from 8,400 to 25,700 and three coke and by-products manufacturers, from 14,400 to 21,600. Two plants reporting the manufacture of sugar had values of 13,100 to 18,400 gallons.

Industrial Water Use By State

133. Delaware The industrial water use in the State of Delaware amounts to more than 140 mgd, approximately 7% of the basin total (Table 9), and includes 72 mgd of brackish water. Ninety percent of this water comes from surface supplies. Only 17 mgd are used from municipal systems whereas 80% is self-supplied. Table 10 shows the major water using industry in the State of Delaware is the chemical products. This industry uses 65 mgd or more than 45% of the total State industrial water use.

134. New Jersey The total industrial water use in New Jersey is more than 440 mgd, 80% of which is supplied from surface waters. Self-supplied industrial waters in New Jersey amount to 92% of the total use, with only 37 mgd being provided by municipal systems. The industry with the largest water use in New Jersey is the chemical and allied products industry, using 189 mgd or 42% of the total. Petroleum and coal products using 61 mgd, and paper and allied products with 40 mgd are second and third in order of importance.

135. New York The industrial water use in New York is only 1 mgd, primarily used in the food and kindred products industry.

136. Pennsylvania The industrial water use in Pennsylvania is more than 1,500 mgd, or 72% of the total industrial water use within the basin. Of this, 93% is supplied from surface waters. With only 8% supplied from municipal sources, self-supplied water amounts to 92% of the total use. The largest industrial user of water in Pennsylvania is the primary metals industry, using more than one-third of the State's total. The petroleum and coal products industry, and the chemical and allied products industry rank second and third, with 319 and 167 mgd, respectively. Anthracite mining in Pennsylvania accounts for more than 100 mgd.

Industrial Water Use By Service Area

137. The industrial water use within the basin proper has been sub-divided into the Sub-regions delineated originally in the Municipal Water Use Section. The data are presented in Table 12. Sub-region E, the Philadelphia Metropolitan area with its high degree of industrialization is the largest user of industrial water in the basin. The second largest region is Sub-region C, the Bethlehem-Allentown area. The smallest water use is Sub-region H, the Southern Basin and Coastal area, the least industrialized of these areas.

TABLE 12

INDUSTRIAL WATER USE IN DELAWARE RIVER BASIN BY SUB-REGIONS+
Annual Average for 1955
(Million Gallons per Day)

Sub-regions	Municipally Supplied Ground	Municipally Supplied Surface	Self-Supplied Ground	Self-Supplied Surface	Sub-Total Ground	Sub-Total Surface	Total
A	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-
C	6	27	34	325	40	352	392
D	-	11	4	44	4	55	59
E	17	91	85	1,059	102	1,150	1,252
F	1	17	15	196++	16	213++	229++
G	-	5	22	108	22	113	135
H	1	-	25	6	26	6	32
Total	25	151	185	1,738++	210	1,889++	2,099++

\+ Includes that portion of each Sub-region lying within the Delaware River Basin only.

++ Includes 160 mgd brackish water used in Delaware and New Jersey. (See Footnote to Table 9.)

Summary

138. The industrial water use in this report has been limited to a consideration of the water used only within the basin proper. This has been further limited by considering only those industries and plants using more than 20,000 gpd, this representing 95% of all industrial water use. Separate consideration was given to the steam electric generating industry in Section VII.

139. Of the total water use of two billion gallons per day for industrial use, more than 90% is self-supplied by industry mainly from surface sources and 160 mgd from brackish water sources. The major water using industries in the basin are the primary metals industry, the chemical industry and the petroleum products industry in that order. The total use for each state generally parallels the basin-wide totals. Special concentrations of industries exist such as the petroleum industry in Delaware and Pennsylvania and the primary metals industry in Pennsylvania. Chemical industries are generally located in Delaware, New Jersey, and Pennsylvania. The water use of the industries within the basin represents three times the total water use of the municipal systems in the same area.

SECTION VII - TOTAL MUNICIPAL AND INDUSTRIAL WATER USE

Introduction

140. General The separation of water use into municipal and industrial categories introduces a duplication in determining the total water use for the basin. This section of the report integrates the municipal and industrial water use and eliminates the overlap between the two. This overlap is evident considering that the Municipal Water Use Section includes the water supplied by municipal supplies to industry, and the Industrial Water Use Section includes this plus the self-supplied industrial water. This total water usage does not include water drawn for agricultural and rural supplies, which is reported on by the Department of Agriculture in their Appendix.

141. Limitations The Industrial Water Use Section limits coverage to the basin area only. Therefore, this summary section must be limited to this same area. It will not include any treatment of the neighboring service area, nor will it include any breakdown of the use of the waters diverted from the basin by New York City and through the Delaware-Raritan Canal. These diversions are to be treated as gross figures only and are so footnoted in the tables of this section.

142. Comparisons of the total water use in the basin and the state portions of the basin are included. These figures do not represent the addition of the municipal and industrial data previously presented because some water use for industrial purposes was included in the municipal water use totals. Appropriate adjustments were made resulting in the following tables of the total water use. Again, it is to be noted that the summation in this section is for the Delaware River basin only and does not include the neighboring service area.

Total Water Use in the Delaware River Basin

143. Total basin water use The total municipal and industrial water use within the Delaware River basin amounts to more than 6,000,000,000 gpd. This withdrawal of water from the streams, lakes,

wells and springs within the Delaware River basin services a population of 5 million persons. The per capita withdrawal on this basis is equal to 1,200 gpd. As will be noted in the footnote to Table 13, these figures do not include the diversions of basin waters to New York City and through the Delaware-Raritan Canal. Since no division of these supplies was available as to domestic, commercial or industrial use, it was considered advisable to treat these as diversions to be added to the gross total municipal and industrial water use only. When these diversions are included, the use of basin water becomes approximately 6.4 billion gpd and services a population of approximately 7.5 million persons. (See Figure 4.)

144. Withdrawal rates The basin has a drainage area of 12,765 square miles and with a withdrawal of 6.4 billion gpd, the withdrawal per square mile of the basin water for municipal and industrial use approximates 0.50 mgd. Discounting the diversions of 388 mgd, the withdrawal of 6 billion gpd averages about 0.47 mgd per square mile. The withdrawal rate for the United States for municipal and industrial use is 0.04 mgd per square mile. This would indicate that the withdrawal rate in the Delaware River basin is approximately twelve times greater than the rate for the country as a whole.

145. Steam electric generation water use In Table 13, the industrial water use for steam electric generation is listed separately. This use of 3,400 mgd represents more than half of the total water use within the basin. Of this total, 650 mgd is brackish water. All of this water is withdrawn from surface supplies for use as a coolant and returned to the stream within close proximity to the point of withdrawal.

146. Self-supplied industrial water use Self-supplied industrial use of water other than the steam electric generation amounts to approximately 1.9 billion gpd, including 160 mgd of brackish water. This is made up of approximately 1.7 billion gpd of surface water and the remainder of ground water. The self-supplied industrial use is approximately three times the total municipal use within the basin.

147. Municipal water use Municipal use within the basin

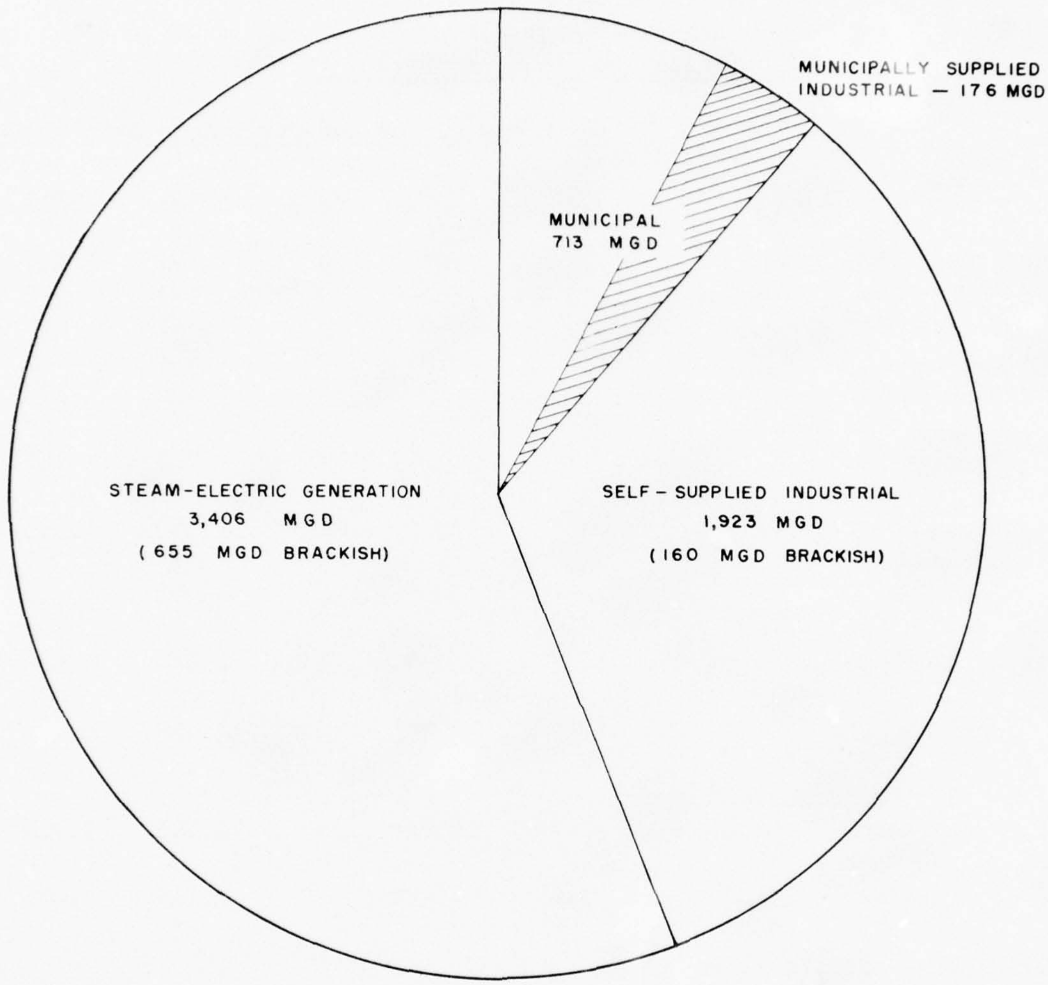
TABLE 13

MUNICIPAL AND INDUSTRIAL WATER USE
IN THE DELAWARE RIVER BASIN°
Annual Average for 1955
(Million Gallons per Day)

	Basin Portion of Sub-regions in Each State				
	Del.	N.J.	N.Y.	Penn.	Total
Municipally Supplied	42	105	9	557	713
Domestic and Commercial	25	68	9	435	537
Ground	9	53	2	31	95
Surface	16	15	7	404	442
Industrial	17	37	-	122	176
Ground	-	18	-	7	25
Surface	17	19	-	115	151
Industrial Self-Supplied	125+	408*	1	1,389	1,923
Ground	17	70	-	98	185
Surface	108+	338*	1	1,291	1,738
Municipal Plus Industrial	167+	513*	10	1,946	2,636
Ground	26	141	2	136	305
Surface	141+	372*	8	1,810	2,331
Steam Electric Generation Self-Supplied Cooling Water	305++	956**	-	2,145	3,406
Ground	-	-	-	-	-
Surface	305++	956**	-	2,145	3,406
Municipal + Industrial + Steam Electric	472+++	1,469***	10	4,091	6,042
Ground	26	141	2	136	305
Surface	446+++	1,328***	8	3,955	5,737
Grand Total	472+++	1,469***	10	4,091	6,042

+ Includes 72 mgd brackish water
++ Includes 305 mgd brackish water
+++ Includes 377 mgd brackish water
* Includes 88 mgd brackish water
** Includes 350 mgd brackish water
*** Includes 438 mgd brackish water
° Includes basin use only and does not include diversions from the basin.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



TOTAL AVERAGE ANNUAL WATER USE IN THE DELAWARE RIVER BASIN 6,042 MGD (815 MGD BRACKISH)

PART A MUNICIPAL AND INUSTRIAL WATER USE U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE	FIGURE 4 TOTAL AVERAGE ANNUAL MUNICIPAL, SELF-SUPPLIED INDUSTRIAL AND STEAM-ELECTRIC GENERATION WATER USE DELAWARE RIVER BASIN 1955

averages 713 mgd. More than 500 mgd of this is for domestic and commercial use. The remainder, or approximately 20% of the total municipal supply, is supplied to industry for their use. Surface waters represent more than 70% of this total municipal supply and this proportion holds true for those municipal supplies utilized by industry.

148. Total basin water use Total water use within the basin as stated before approximates 6 billion gpd. Of this total, only 300 mgd are supplied from ground water sources, or less than 5%. The preponderance of surface water is due to the large use of these waters for steam electric generators, and includes 815 mgd of brackish water use.

Total Water Use by State Portion of Basin

149. Delaware The portion of the State of Delaware within the basin uses approximately 472 mgd for all municipal and industrial water uses, 8% of the basin total. The largest portion of this is the 305 mgd used for steam electric generation of this brackish water. The remainder of 167 mgd is divided with 85% for self-supplied industrial and 15% for municipal purposes. Eighty-seven percent of the self-supplied industrial water comes from surface sources with brackish waters supplying 72 mgd.

150. The drainage area of the basin within the State of Delaware is approximately 1,000 square miles. With a withdrawal of more than 472 mgd, the withdrawal rate is 0.47 mgd per square mile. The rate is the same as that for the basin. The per capita consumption of water on a persons served by municipal supply basis is 1,829 gpd. This is more than one and a half times the rate for the basin and the high degree of industrialization in Delaware for its small population may explain this.

151. New Jersey In New Jersey the total municipal and industrial water use is 1,469 mgd, or approximately 24% of the basin total. Here again steam electric generation accounts for 956 mgd or 65% of the total water use; this includes the use of 350 mgd or

of brackish water. Eighty percent of the remaining water use is self-supplied industrial water, 83% of this coming from surface water sources.

152. The New Jersey portion of the basin covers 2,969 square miles, approximately a quarter of the basin total, and with the consumption of 1,469 mgd, the withdrawal rate is 0.49 mgd per square mile. This is approximately the same as the basin average. The per capita consumption on a population served basis is approximately 1,745 gpd. This is one and a half times the basin average.

153. New York The New York State portion of the basin withdraws a total of 10 mgd and services a population of only 62,000 persons. This total use represents much less than 1% of the basin total. Self-supplied industrial use is 1 mgd, or only 10% of the state total.

154. The drainage area in New York State is 2,362 square miles, or 19% of the total basin area. With the small population and associated low water use, New York State has the smallest withdrawal rate within the entire basin, a rate of less than 0.01 mgd per square mile. The per capita consumption is 161 gpd. This is due to the rural nature of the area and its consequent lack of population and industrialization.

155. Pennsylvania The total municipal and industrial water use of the Delaware River basin portion of Pennsylvania is more than 4 billion gpd, averaging 68% of the total water use within the basin. More than half of this water use or 2,145 mgd is used for steam electric generation. This is all self-supplied surface water. All self-supplied industrial water used for purposes other than steam electric generation amounts to 1,389 mgd, or 72% of the remaining water use; 93% of this is supplied from surface waters.

156. Pennsylvania's portion of the basin area is 6,422 square miles, or 50% of the total. This drainage area serves a population of 3,900,000 representing 77% of the total population served within the basin. The water use of 4.1 billion gpd represents 68% of the basin total. Pennsylvania has the highest withdrawal rate within the basin,

TABLE 14

SUMMARY OF TOTAL MUNICIPAL AND INDUSTRIAL WATER USE
IN DELAWARE RIVER BASIN°
Annual Average for 1955

	Basin Portion of Sub-regions in Each State				
	Del.	N.J.	N.Y.	Penn.	Total
Population Served+					
(Thousands)	258	842	62	3,902	5,064
Percent	5	17	1	77	-
Water Use					
(mgd)	472	1,469	10	4,091	6,042
Percent	8	24	1	68	-
Area in Basin*					
(Square Miles)	1,004	2,969	2,362	6,422	12,765
Percent	8	23	19	50	-
Per Capita Use					
(gpd)	1,829	1,745	161	1,048	1,193
Withdrawal Rate					
(mgd/sq. mile)	0.47	0.49	0.004	0.64	0.47

* Also Maryland - 8 square miles
° Includes basin use only and does not include diversions from the basin
\+ Population served by municipal systems

averaging 0.64 mgd per square mile. The per capita consumption is approximately 1,000 gpd or less than the basin average of 1,200 gpd. The City of Philadelphia represents a large portion of the Pennsylvania population and water use.

Summary

157. This section has presented a summary of the total municipal and industrial water use within the Delaware River basin and is summarized in Table 14. This usage does not include waters withdrawn for agricultural or rural supplies, nor does it include diversions from the basin for New York City or through the Delaware-Raritan Canal. The total water use is approximately 6,000,000,000 gpd and services approximately 5,000,000 persons. The greatest user of water within the basin is that portion in the State of Pennsylvania. The source of supply for 95% of all of the basin water used is surface waters. Ground water plays a predominant part in only the coastal plain areas of Delaware and New Jersey. However, reuse of waters allows unusually high withdrawal rates of approximately .5 mgd per square mile for the basin, with even higher rates for the basin portion of Pennsylvania. Per capita consumption on a population served basis approximates 1,200 gpd for the basin as a whole, but varies from this median to a high of 1,800 gpd in the State of Delaware to a low of 200 in the State of New York.

SECTION VIII - NEW YORK CITY WATER SUPPLY*

Introduction

158. History New York City began to assume its modern complexion on January 1, 1898 when a consolidation of the present five Boroughs was effected. Prior thereto, each segment had existed as an entity unto itself, providing independently for the needs of its citizens. Thus, at the time of joining, each brought to the union along with its other facilities and capabilities, the diverse and disassociated water supply systems which, up to then, had been developed for its particular purposes. For the newly organized metropolis of 3.4 million people, with a daily water need somewhat in excess of one-third billion gallons, the result was far from satisfactory. Certain improvements were in the making. It was recognized that a vast expansion lay ahead, but few foresaw a populace of eight million by the fifties with a practically coincidental water demand of one billion gallons daily.

159. Sources The water sources were scattered. They included, at the time of consolidation, the Croton and Bronx-Byram source supplying the Bronx and Manhattan, a well system on Long Island supplying Queens and Brooklyn and local wells on Staten Island. An expansion of the Croton system had been recommended and this was being effected. Citizen groups and government people were searching for a solution, but because of political undercurrents, there was no unanimity. The situation was difficult.

160. Burr-Hering-Freeman Report The most praiseworthy effort to resolve the matter was initiated by New York's Mayor Seth Low in 1903 when an engineering commission, composed of

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* Prepared by the staff of the Board of Water Supply, City of New York for the U. S. Public Health Service Appendix on Municipal and Industrial Water Use in the Delaware River Basin.

William H. Burr, Rudolph Hering and John R. Freeman, was appointed to explore all possibilities and to make appropriate recommendations. The result was the now famous Burr-Hering-Freeman report titled REPORT OF THE COMMISSION ON ADDITIONAL WATER SUPPLY FOR THE CITY OF NEW YORK, brought forth on November 30, 1903. This 980 page document searched the entire field and advanced many proposals some of which have since been implemented and others that are still regarded by some as having merit. Outstanding was a proposal to develop the Catskill watershed.

161. First Board of Water Supply Simultaneously, an aroused public clamored for action. Public officials, and eventually the State Legislature, responded by providing for a New York City Board of Water Supply, headed by three commissioners having life tenure. The year was 1904 and the leading advocate was the then Mayor, George B. McClellan. The measure became effective the following year and Mayor Mc Clellan appointed the first Board of Commissioners. Thus was set the stage for the City's present water supply system and the manner in which it was subsequently to be effectuated.

Present Supply

162. Sources New York City depends upon five distinct sources for its water supplies:

1. The Croton Watershed
2. The Catskill Watershed
3. The Delaware and Rondout Watersheds
4. The Long Island Supply (for emergency)
5. The Staten Island Wells

163. Croton The Croton source, originally developed between 1835 and 1842, was later expanded as the City's need demanded. As it generally exists today, it was completed in

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REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)
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1910. It now embraces a catchment area of some 375 square miles which is almost totally contained in the New York counties of Dutchess, Putnam and Westchester.

164. Catskill The next to be built was the so-called Catskill system that draws from the Esopus and Schoharie areas of the central and eastern Catskill mountains on the west side of the Hudson River. Built in two stages, the first stage comprising the Esopus development with a drainage basin of 257 square miles, was placed in operation at about the end of 1915. The second stage, referred to as the Schoharie development, has a drainage area of 314 square miles which went into operation in 1924.

165. Rondout-Delaware The most recent source to be developed is the integrated Rondout-Delaware system which draws from streams on the westerly slope of the Catskill Mountains. Generally referred to as the Delaware development, its first stage included a reservoir on Rondout Creek, tributary of the Hudson River, and another on the Neversink River, tributary to the Delaware. The second stage added a reservoir, known as the Pepacton Reservoir, on the East Branch of the Delaware and the third stage, now under construction, will result in the ultimate establishment of a reservoir (at Cannonsville) on the West Branch of the Delaware. The Rondout development has a watershed area of 95 square miles and the Delaware developments, 93 square miles, 372 square miles and 450 square miles, for Neversink, Pepacton and Cannonsville respectively, totaling 1010 square miles. All of these lie within the confines of New York State. Rondout functions as the receiving and distributing reservoir for the system. First in order of completion, it was placed in emergency service on April 5, 1944 and in regular operation on June 18, 1951, followed by regular operation of the Neversink development on January 1, 1954 and the East Branch (or Pepacton) development on September 1, 1955.

166. Long Island The Long Island source comprises the Ridgewood system, a series of ponds and driven wells originally developed by the pre-consolidation City of Brooklyn, and the Queens system of locally driven wells similarly developed for the needs of that Borough. These two systems have declined appreciably in importance during recent years and are now reserved for emergency use.

167. Richmond The Richmond (Staten Island) wells, yielding only about 5 mgd, supplement the upland gravity supply to that borough at present.

Distribution System

168. General The waters from the upland basins are gathered and distributed by some controlled lakes and ponds. Each of the three principal upland systems has its own network of supply conduits leading to the City. The Croton supply is, for the most part, delivered to and into the city by the New Croton Aqueduct (circa 1890). It is a low level gravity supply and for its full utilization it is necessary to pump a goodly portion of the supply within the City.

169. Aqueducts The Catskill, a high level supply, is delivered by grade and pressure aqueduct from Ashokan Reservoir, on the Esopus Creek, to Kensico Reservoir in central Westchester County and thence to Hillview Reservoir at the City Line. The Rondout-Delaware system, similarly a high level supply, is delivered by pressure tunnel from the Rondout Reservoir to the West Branch Reservoir of the Croton system, thence to Kensico and Hillview Reservoirs. These interconnections plus hydraulic pumping stations at Croton Falls and Cross Rivers reservoir of the Croton system make possible the enroute intermixing of the waters of the three systems. This permits some degree of quality control, - safeguards against system imbalance and provides a certain economy of operation. For further safety and quality control, bypass connections on the line of the

Delaware Aqueduct are provided at the West Branch, Kensico and Hillview Reservoirs and on the line of the Catskill Aqueduct at the latter pair of reservoirs. Hillview Reservoir, together with a number of small regulating reservoirs within the City, receives the upland flows, holds them against demand and smooths out fluctuations.

170. City Tunnels The high level waters are brought into the City through two deep tunnels in rock known as City Tunnel 1 and 2 respectively. City Tunnel No. 1 underlies Manhattan and crosses under the East River to enter Brooklyn. It terminates in the downtown section of Brooklyn. City Tunnel No. 2 passes through the Bronx, under the East River and Rikers Island to Queens, thence through Brooklyn, joining City Tunnel No. 1 at Fort Green Park and continuing to the Red Hook Section of Brooklyn for possible future extension. Pipelines from the terminal shafts extend southward through Brooklyn for local distribution and to supply a pair of submarine pipelines crossing the Narrows to Richmond. Similarly, cross-bay pipelines serve the Rockaways from connections to trunk mains in Brooklyn.

171. Street Mains At key locations along the two City tunnels, there are riser connections to the street main systems. As of December 1957, there were nearly 5,600 miles of distribution mains throughout the city, varying in diameter from 1 1/2" to 72". About 159,000 valves were in place along these lines with 86,010 fire hydrants. There is also a high pressure fire-service system which, in 1957, totalled about 174.5 miles, had 6,600 special valves, and 4,100 high pressure hydrants.

Water Use - 1955

172. New York City During 1955 the water use statistics for New York City were as follows:

Locality	Population (1000)	Consumption (mgd)	Per Capita (gpd)
Manhattan and the Bronx	3,482	575.8	165.4
Brooklyn	2,731	329.6	120.7
Queens	1,718	178.7	104.0
Richmond	217	25.8	118.9
New York City Total	8,148	1109.9	136.2

173. Outside Areas The City of New York is also required, under law, to supply the waters requested by those outside communities through which the City's conduits happen to pass or within whose areas the City has built portions of its far flung works. Water so drawn is paid for, but must nevertheless be considered in the City's consumption statistics. The total so provided in 1955 amounted to 45.3 mgd.

174. Range of Flows Maximum and minimum statistics during 1955 were as follows:

	During any one day (mg)			
Locality	Maximum	Date	Minimum	Date
Manhattan and the Bronx	719.7	Aug. 5	464.5	June 11
Brooklyn	412.8	July 5	268.1	Mar. 27
Queens	185.8	Aug. 2	109.7	Jan. 16
Richmond	39.3	Aug. 2	18.0	June 12
New York City Total	1,328.2	Aug. 2	902.7	Jan. 1

175. Yield of System The safe dependable yield of the combined New York City sources during 1955 was as follows:

Croton	330 mgd
Bronx-Byram	10 "
Catskill	555 "
Delaware-Rondout	120 "
Delaware	490 "
Richmond	5 "
Total	1,510 mgd

Water Use - 1957

176. New York City During 1957 the water use statistics for New York City were as follows:

Locality	Population (1000)	Consumption (mgd)	Per Capita (gpd)
Manhattan and the Bronx	3,486	583.2	167.2
Brooklyn	2,718	368.9	135.7
Queens	1,730	187.8	108.6
Richmond	237	29.1	122.8
New York City Total	8,171	1,169.0	143.0

177. Outside Areas The City of New York is also required, under law, to supply the waters requested by those outside communities through which the City's conduits happen to pass or within whose areas the City has built portions of its far flung works. Water so drawn is paid for, but must nevertheless be considered in the City's consumption statistics. The total so provided in 1957 amounted to 57.2 mgd.

178. Per Capita Use The gallons per capita per day for earlier years, on a City-wide basis were:

1954	130.7	1957	143.0
1955	136.2		
1956	136.1		

179. Range of Flows Maximum and minimum statistics during 1957 were as follows:

Locality	During any one day (mg) Maximum	Date	Minimum	Date
Manhattan and the Bronx	781.2	June 17	470.6	Nov. 24
Brooklyn	466.1	June 17	315.3	Feb. 24
Queens	194.9	July 22	107.9	Oct. 26
Richmond	39.4	June 17	19.6	April 19
New York City System	1,483.7	June 17	980.6	Nov. 24

180 **Yield** of System The safe dependable yield of the combined New York City sources during 1957 was as follows:

Croton	325 mgd
Bronx	5 "
Catskill	555 "
Delaware-Rondout	120 "
Delaware	490 "
Richmond	5 "
Total	1,500 mgd

Future Water Requirements

181. Future Needs The City's future position, waterwise, appears quite secure at this time. Under permission by Decree of the Supreme Court of the United States, the West Branch of the Delaware River is being developed to provide an additional supply of 310 mgd which should become available during the early 1960's to raise the basic supply to an estimated 1,810 mgd. Based upon the City's estimated growth in population and consequent water requirements, as well as the requirements of outside communities supplied by the City under law, it is estimated that a yield of 1,810 mgd should care for the City's needs and obligations to about the end of the century. (See tabulation below)

ESTIMATED FUTURE POPULATION
and
WATER SUPPLY REQUIREMENTS
of
THE CITY OF NEW YORK

Year (1)	CITY Population (1000) (2)	CITY Consumption (mgd) (3)	Supplied to outside Commun. (mgd) (4)	Total Consumption (mgd) (5)
1950	* 7,903	953	29	982
1960	8,403	1,319	50	1,369
1970	8,854	1,443	80	1,523
1980	9,312	1,574	105	1,679
1990	9,730	1,693	125	1,818
2000	10,115	1,810	145	1,955
2010	10,659	1,961	165	2,126

*U. S. Census Population 7,892,000 as of April 1, 1950

182. Population Forecasts This estimate of future population growth within the City is a medium series forecast. It indicates, between the years 1950 and 2010, an annual rate of increase of about one-half of one percent.

183. Consumption Total consumption in the City (Column 3), based upon total population and per capita consumption, reflects an annual increase in per capita of 0.6 gallons per day, 1960 to 1980, and an increase thereafter of 0.5 gallons per day to the year 2010.

Delaware Development Operations

184. General Warranting special mention in any report dealing with Delaware water resources are the conditions and circumstances attending the city's use of developments created by it in the Delaware watershed.

185. Supreme Court Decree Under the Amended Decree of the U. S. Supreme Court, dated June 7, 1954, which modified and amended the Decree issued earlier under date of May 25, 1931, New York City was authorized to divert from the Delaware River watershed (in New York State) 440 mgd until the city had completed and placed in operation its reservoir (Pepacton) on the East Branch of the Delaware River, 490 mgd after the completion and commencement of operation of this second development, and 800 mgd after the completion of its reservoir at Cannonsville on the West Branch of the Delaware. This permission to divert carried certain parallel conditions and obligations for the release of compensating waters from the several basins during the periods of low natural flow in the river, - all of which are specified in the Amended Decree.

186. River Master Both the releases to and the diversions from the Delaware River, by the City of New York, are made under the supervision and direction of a River Master, who shall be the Chief Hydraulic Engineer of the U. S. Geological Survey, or such other engineer of that Survey as shall be designated by the Chief Hydraulic Engineer.

187. First Phase The first phase of operation, which permitted a diversion of 440 mgd (which incidentally was also in accord with the requirements of the original Decree) became effective with the placing in regular service of the Neversink development on January 1, 1954.

188. Second Phase The second phase, permitting a diversion of 490 mgd, went into effect on September 1, 1955.

189. Diversions Computed from June 1 to the end of May of the following year, in accordance with the Amended Decree, diversion by the City for the 1957-1958 period averaged 222.8 mgd. Releases to the river from Neversink and Pepacton Reservoirs during the same interval (12 months) aggregated 90,771 million gallons, the greater portion of which 70,042 mg, was released to augment the natural low flows during the June 15th to December 8, 1957 period, as follows:

1957 SEASONAL RELEASES

Period	Million Gallons	Million Gallons Per Day	Cubic Feet per Second
June 15-30 incl.	4431	277	429
July	17641	569	880
August	17207	555	859
September	12684	423	654
October	10255	331	512
November	7153	238	368
December 1 - 8	671	84	130
Total	70042	396	613

190. Flow at Montague The resultant flow at Montague N. J., the controlling river station as specified in the Decree, averaged 1650 cfs for the overall period from June 15 to December 8.

Conclusions

191. General In conclusion, a note of caution seems necessary in regard to the general reliability of population and water yield forecasts for the City of New York. While all predictions are made with great care and an eye upon trends over all of the years of record, unforeseeable changes are possible that cannot be evaluated. The volume of demand is not entirely within the City's discretion since certain areas beyond the City must be supplied when necessary, according to law. It is known that suburban expansion, particularly north of the City, is accelerating. Despite a tendency on the part of these northern suburbs to develop and to rely upon water supply systems of their own, the time must come when, having exhausted their local potential, they will have to draw from the lines of the City of New York. In a further sense, this northern development

also cuts the yield of upstate watersheds. The urbanization of rural catchment basins not only alters the runoff and water-producing character of the areas, but also increases the pollution burden with resultant deterioration of the quality of the waters flowing from the region, sometimes to the point of compelling abandonment of part of the watershed.

192. Thus growth imposes its own weight upon both consumption and supply. Since the manner, extent and cause of growth are complex and fortuitous, the forecaster must be prepared to revise his best estimates for both demand and supply as soon as circumstances may command. The statistics and conclusions above presented are accordingly offered as the best now determinable, but always with the reservation that tomorrow's events may seriously change today's curves.

SECTION IX - MUNICIPAL WATER SUPPLY - CITY OF PHILADELPHIA*

Introduction

193. History The foundation of the present municipal water system of the City of Philadelphia was laid in 1801 with the inception of the first Philadelphia Works in December of that year. The first Philadelphia Works served only the City proper of those days, an area of less than two square miles. In 1854, following the consolidation of the City proper with the townships, boroughs and districts of Philadelphia County, the water works of the various entities were gradually assimilated by the Philadelphia Works until the water system for the entire County became the responsibility of the City. At that time, few could envision the tremendous expansion of the system which would by the middle nineteen fifties serve a populace of nearly two and one-quarter million in an area 130 square miles with three hundred and seventy million gallons per day (mgd). The Water Department's one hundred and fifty-eight years of growth reflect periods of decay occasioned by indifference or financial difficulties followed by periods of revitalization resulting from the pressure of non-deferable needs. Today, the Philadelphia Water Department is again in a "golden era", now being engaged in a 52 million dollar program of reconstruction and modernization to satisfy its present needs and near future requirements.

194. Sources As it was in the beginning, the Delaware and Schuylkill Rivers are now, and may for quite some time in the future, be the sources of raw water supply. Prior to 1899, the City was served with untreated water channeled directly through reservoirs from these Rivers. Dissatisfaction with the quality of water and the problem of disease resulted in the adoption of the recommendations set forth in the Rudolf Hering Report of 1899 and the subsequent construction of filters. Later, chemical treatment was adopted to aid in the battle

*Material prepared by the Water Department, City of Philadelphia, Penn. for the U. S. Public Health Service Appendix on Municipal and Industrial Water Use in the Delaware River Basin.

against pollution. In recent years the Water Department has taken extensive measures to protect the Rivers from contamination by the construction of three modern sewage treatment works and many miles of large interceptor sewers. Today, the Schuylkill supplies half of the City's water. However, there are existing practical restrictions which preclude increasing the amount taken much beyond current withdrawals. Therefore, practically all future annual demand increases must be met from the Delaware River, and the rated capacities of filter plants (by 1963) on both Rivers have been distributed on this basis. The City of Philadelphia is necessarily concerned with any factor that affects the quality or quantity of either stream. Should low flow augmentation be provided on the Schuylkill River, a high withdrawal rate during drought periods would be assured tending to firm the Delaware supply at the same time. However, to take advantage of low flow augmentation by increasing withdrawals from the Schuylkill much beyond existing average rates (see paragraph 198 and 211) would require greater filtration capacity than is being provided on the Schuylkill and would necessitate retirement of part of the brand new filtration facilities on the Delaware River.

195. <u>1946 Report of the Board of Consulting Engineers</u> The program for expanding and modernizing the City of Philadelphia's water works is outlined in two reports: (a) A report made by Morris Knowles, Inc, for the Director of Public Works in 1940; (b) A report made by the Board of Engineers for the Mayor's Water Commission in 1946. The 1940 report was of a preliminary nature. The basic engineering planning for the water works system has been based upon the 1946 report, modified from time to time by individual studies which have brought up to date the various projects as they became ready for construction. Present projects of the Water Department, along with some of the planning for the next twenty-five years, are to be a considerable extent in accord with recommendations of the 1946 report. The Board of Consulting Engineers in 1946 recommended Philadelphia's current filter reconstruction program and postponement of a descision to obtain purer water from an upland source from the upper Delaware River, primarily on the basis of cost. It is the considered opinion of the Water Department that Philadelphia will not find it necessary to go upstream on the Delaware River for at least fifteen to twenty years. Therefore, any decision to relocate Philadelphia's water sources

must be deferred for the future, although this matter must be kept under continuous study.

196. Water Department, City of Philadelphia In 1952 the new Philadelphia Home Rule Charter resulted in the reorganization of the Water Department. Complete responsibility for design, construction and operation of both the water and the sewage systems was assigned to the Water Department. The Charter also made the Water Department self-sustaining and gave it the power to fix rates under standards set by the City Council. Reorganization and vastly improved financial strength brought forth a resurgence of activity and provided a firm foundation for operating the municipal water system as a modern utility.

Present Supply

197. Sources The City of Philadelphia depends on two sources for its water supplies:

(a.) The Schuylkill River
(b.) The Delaware River

198. Schuylkill River About fifty per cent of Philadelphia's present demand is drawn from the Schuylkill by four filter plants located along the banks of the river within the City limits. Three filter plants are situated on the east bank, namely: The Upper Roxborough Filters, the Lower Roxborough Filters and the Queen Lane Filter Plant the fourth, on the west bank, is the Belmont Filter Plant. In the near future, the Upper and Lower Roxborough Filter Plants will be abandoned; approximately fifty-five per cent of the water now supplied by these filters will be provided by the Queen Lane Plant, with the remainder being made up from the Torresdale Filter Plant on the Delaware River. However, the future rated capacity of Schuylkill filter plants will remain about the same as present (200 mgd - see paragraph 211.)

199. The Schuylkill water supply usually has more than twice the total hardness as measured in parts per million (ppm) found in the Delaware River supply:

Hardness as Yearly Average		
Year	Schuylkill	Delaware
1958	135 ppm	57 ppm
1957	166	64
1956	129	55
1955	143	50

200. During the past 15 years, the Commonwealth of Pennsylvania has carried on an extensive program for pollution abatement which was directed primarily towards the elimination of culm waste originating in the anthracite fields. Practically every community from the mouth of the Schulykill upstream to and including Reading now operates a sewage treatment plant. Upstream from Reading, only Schuylkill Haven has sewage treatment facilities. Despite these anti-pollution measures, the most probable number (MPN) of coliform organisms at the Schuylkill intakes ranged between 23,000 and 53,000 over the years 1956, 1957 and 1958. Early in 1958, Philadelphia received from the Water and Power Resources Board an allocation of 258 mgd from the Schuylkill River which will provide for the overload capacity of new rapid-sand filter plants (rated capacity 198 mgd). The former allocation of 200 mgd granted in 1944 was for slow-sand filter plants of 200 mgd rated capacity (overload capacity was little more than rated capacity). It should be noted that other water users are in competition with Philadelphia for the Schuylkill supply; the Philadelphia Suburban Water Company has been granted simultaneously a provisional allocation of 20 mgd, subject to Philadelphia's prior use. The total flow in the Schuylkill immediately above the Philadelphia intakes was less than 200 mgd on 14 days in the past 27 years.

201. <u>Delaware River</u> There is only one intake on the Delaware River and it supplies the Torresdale Filter Plant; the Plant is within the city proper and located on the west bank of the river. At present the Torresdale Plant processes half of the supply. Almost all future increases in demand will be served from the Delaware River via the Torresdale Filter Plant. The pollution abatement programs of the State and Federal governments along the Delaware have attracted nationwide attention, yet the MPN of coliform organisms averaged 86,000 at the Torresdale Plant in 1956, 113,000 in 1957 and 62,000 in 1958.

202. There are other factors which are involved in the future demands for municipal water supplies in the lower part of the Delaware basin which are of concern to Philadelphia. These include: population increases, the effect of the 40 foot channel on quality and quantity demands in the basin, the effect of releases and authorized diversions by New York City, possible discontinuance of the use of the Schuylkill River as an important source of supply for Philadelphia, adequacy of underground sources to serve the increasing population of Lower Bucks County and low flow augmentation as an element of control of both quantity and quality of water in the basin.

Waterworks System

203. General Raw water taken from the Schuylkill and Delaware Rivers at Philadelphia intakes is unsuitable for use without elaborate treatment. Philadelphia utilizes special and standard measures to process the raw water before it is a fit, potable commodity. In essence, the delivered finished product is the result of the following procedures: Pumping of raw water from the rivers, impoundment in pre-sedimentation basins; flocculation and precipitation; filtration by either slow sand or rapid sand type filters, addition of chemicals at various stages, storage in filtered water tanks, basins or reservoirs, finally, fed into arterial supply mains by pumps or by gravity to be distributed to the consumer through thousands of miles of pipes of varying diameter. The Distribution System is divided into ten pressure service districts, five of which have distributing storage. Filtered water from the Delaware is pumped at two pumping stations into four service districts, two of which have equalizing storage. Supply from the Schuylkill is delivered from clear water basins by gravity to four service districts and by pumping to four service districts, one district has equalizing storage. The Water Department also operates a high pressure fire system, separately from the domestic water distribution system, which protects the high risk and high value districts of the city. Two pumping stations and a separate distribution system comprise the high pressure fire system.

204. Treatment Plants Philadelphia's principal treatment facilities are in the process of being rebuilt and completely modernized. During the year of 1959 a new $25-million treatment plant was placed on an operational status at Torresdale. The new Torresdale Treatment Plant on the Delaware River is a modern rapid-sand type with various automatic control features and has an average rated capacity of 282 million gallons daily with an overload capacity of 423 million gallons daily. Studies and designs in the modernization of the Belmont Plant were started in 1958 with the entire work tentatively scheduled for completion in 1963. Conversion of the slow-sand filters to rapid-sand filters at Belmont to augment the existing rapid-sand type filters there, will provide the plant with a rated capacity of 78 million gallons per day. A new pre-treatment plant with automatic controls, was opened at Queen Lane in 1955. Conversion of remaining slow-sand filters at Queen Lane to rapid-sand filters is now taking place. Queen Lane will have a daily average capacity of 120 million gallons when this entirely rebuilt and modern plant is completed in 1960. The Roxborough works are to be abandoned shortly after the last of these plants are completed. The following chemicals are employed; chlorine, activated carbon, sodium hexametophosphate, alum, fluoride, lime, sodium chlorite, sulphur dioxide and copper sulphate.

205. Street Mains As of December, 1958, Philadelphia had nearly 3000 miles of distribution piping, ranging in size from three inches to ninety-three inches in diameter. Approximately 64,300 valves are installed in the distribution piping with 24,300 fire hydrants. The high pressure fire system has sixty-three miles of pipe from eight to twenty inches in nominal diameter, about 1,870 valves and 1,060 special high pressure fire hydrants.

Water Use - 1953 - 1957

206. City of Philadelphia:

Year	Est. Population	Consumption (mgd)	Per Capita Use (gpd)
1953	2,130,000	370	174
1957	2,200,000	352	160

207. Outside areas Water service rendered outside the limits of the City was minor; standby fire service was provided for a few properties and domestic service to less than 200 customers.

208. Per Capita Use:

Year	1953	1954	1955	1956	1957
Rate gpd	174	171	171	162	160

209. In the years prior to 1953, per capita consumption rose continuously. The decline in the average consumption for the above years from 1953 onward, was predicted and can be attributed directly to higher water service charges, intensified leak and waste programs, to a decline in intensity of industrial activity since 1953, and to the universal metering program started in 1953. (Universal metering was about 99 per cent completed in 1958). The consumption of water during the first ten months of 1959 indicates that this downward trend in per capita use is being reversed.

210. Range of Consumption Rates:

	1953	Rate (mgd)	1957	Rate (mgd)
Maximum hourly (approx.)	2 Sept.	627.0	18 June	595.0
Maximum daily	2 Sept.	496.5	18 June	455.5
Minimum daily	1 Feb.	286.9	1 Dec.	290.1

211. Filtration Capacity:

	1953 Rated Capacity (mgd)	Proposed Capacities Rated (mgd)	Overload (mgd)	River
Torresdale	200	282	423	Delaware
Queen Lane	100	120	150	Schuylkill
Belmont	70	78	108	Schuylkill
Roxborough (upper and Lower)	30	0	0	Schuylkill
Totals	400	480	681	

212. In 1953 most of the filters were of the slow-sand type. Complete conversion to rapid-sand filters is in progress and is scheduled for completion by 1963.

Future Water Requirements

213. Future Needs All present and future plans of Philadelphia specify complete treatment of water whether taken from the present intakes on the Delaware and Schuylkill Rivers or from an upland source on the Delaware. Retention of the present intakes, in general, is based on the premise that the clean-stream programs will continue to be effective in controlling the level of pollution load in both rivers, that the present quality of both streams will not be seriously impaired by future developments affecting the rivers, and that advances in water treatment technology will keep pace with the more critical treatment problems anticipated in the future. The future estimated needs of the City of Philadelphia for raw water, whether taken at the intakes or from an upland source are tabulated below.

ESTIMATED FUTURE POPULATION

and

WATER SUPPLY REQUIREMENTS
of
THE CITY OF PHILADELPHIA

Year	Population (1000)	Raw Water, Average Annual** (mgd)	Raw Water, Maximum Day** (mgd)
(1)	(2)	(3)	(4)
1950	2,072*	--	--
1960	--	400	500
1970	--	450	560
1980	2,500	500	620
2010	--	540	670

*U. S. Census Population 2,071,605 as of April 1, 1950

**Direct withdrawals from sources of supply

214. Population Forecasts The above estimate of future population growth for 1980 is a "medium series, trend forecast." The "trend" estimates based essentially on the supposition that current trends will continue for most areas but be modified in others by planning factors which have official status and are scheduled for completion prior to 1980. Between the years of 1950 to 1980 an annual rate of increase of approximately 0.7 of one per cent is indicated. Population forecasts were derived by the Philadelphia City Planning Commission and reported in their publication of February, 1957 entitled, "Pilot Plan, a Study for the Comprehensive Plan for the Development of Philadelphia."

215. Raw Water Maximum Day Column (4) gives estimates of total maximum amounts of raw water which must be withdrawn directly from sources(s) of supply over each annual peak 24-hour period. Average annual raw water demands cannot be considered as sole criteria for future needs, availability of peak raw water rates is also essential.

216. It is to be noted that raw water rather than consumption figures have been cited, as the latter would be misleading in evaluating source requirements. Average annual raw water drafts at river intakes will exceed average annual consumption by about five percent, the amount of water which will be diverted to clean filters by backwashing. The maximum annual 24-hour consumption and related consumption at peak hours are normally greater than filtration rates at the same times; filtered water storage at treatment plant sites, situated between the filters and the distribution system make possible this rate attenuation. For the purpose of illustration, if the amount of raw water withdrawn from source(s) was restricted to a constant draft of 540 mgd at about the year 2010, a minimum equalizing storage (not now in existence) of 5.6 billion gallons would be needed, assuming full storage capacity available in early June. At the present time, withdrawal from existing sources at river intakes is a direct reflection of consumer demands on treatment facilities. The amount of raw water equalizing storage now available is only 0.017 billion gallons, and plans do not call for any increase in the future.

Delaware Development Operations

217. General Philadelphia's water needs indicated by concomitant planning, together with the needs for other public water supplies utilizing the waters of the lower Delaware Basin may be affected directly or influenced to a considerable degree by the ultimate plan for the comprehensive development of the Delaware Basin, by any final plan for the future exploitation and control of the Delaware River, and by increasingly greater authorized usage by New York City. Philadelphia is vitally concerned that any plans for the river do not restrict or preclude any possible future development of Philadelphia and its environs.

218. Diversions and Releases The full effects of the New York diversions and releases will not be realized until all of their proposed structures are in operation. Philadelphia feels that as New York City's demands increase, with subsequent increases in diversion and a gradual diminishing of the "bonus" releases, a condition will result which may be critical for Philadelphia sometime between 1970 and 1975.

Conclusions

219. General Philadelphia's forecasts of population and water consumption were derived after intensive analysis and appraisal of past trends and records with due consideration to the possible impact expected major changes may have on these predictions. These forecasts should not preclude adjustment for additional increases at some later date to include other projects or levels of development not now evident. The population forecast for 1980 reported herein is by no means ultra-conservative since it does not reflect an "ultimate" population-industrial activity situation that could be attained provided all changes anticipated in the comprehensive plan for Philadelphia fully materialized. A "medium series plan method" forecast for Philadelphia gives a 1980 population of 2,836,000 vs the "medium series, trend method" population of 2,500,000 for 1980 cited. The "plan method" forecast represents an "ultimate situation." Consumption estimates given herein could be justifiably revised upward. In response to requests, Philadelphia is tentatively considering supplying water to public institutions and governments outside the City limits. If such service is rendered, consumption predictions would have to be correspondingly increased.

220. Philadelphia has no immediate plans to go upstream on the Delaware River for its source of supply. Attention is called however, to the low, marginal quality of existing water supplies at the present Philadelphia intakes. Further critical degradation in quality or serious impariment in quantity of the present water supplies will hasten a Philadelphia decision on an upland supply. There are myriad factors affecting the quality and quantity of the present Philadelphia water supply, many of which may be resolved by the findings of the present survey being conducted by the Corps of Engineers and by future interstate arrangements and agreements which may arise from the present survey. Philadelphia's position insofar as the future development of the Delaware River is concerned, is that the City has the right to all the water which it requires from the Delaware River, consistent with the rights of others in the basin. The City further desires the right to go upstream on the Delaware River in the future and obtain the water which it needs when conditions require it or when Philadelphians desire it. When and if Philadelphia goes to an upland source, others in the lower basin may want or find it desirable to enter into a cooperative upland supply arrangement.

PART B

STREAM QUALITY

PART B

STREAM QUALITY

CONTENTS

SECTION I - FOREWORD

Scope

1. Purpose The purpose of this Part is to evaluate the various water quality parameters of the Delaware River and its significant tributaries from its headwaters to Delaware Bay. The analysis and interpretation of results and existing data will form a base from which certain future water quality parameters can be estimated under future environmental conditions. The report will serve as a guide for predicting any water quality assets or liabilities attributable to a future change in the flow regime of the Delaware River.

2. Organization This Part offers a factual presentation of the stream quality characteristics of the Delaware River basin from its headwaters to Delaware Bay, interpretation of their significance and their interrelationships. It includes a section on the 1957 water quality survey together with results obtained from the survey, and analyses and interpretations of these data. Existing long term data are examined and any correlations obtained are presented and discussed. The effects of significant tributaries upon the Delaware are also examined and interpreted.

Acknowledgements

3. Appreciation is expressed for the cooperation and assistance given in this study by the Federal, interstate, state and local governmental agencies. The major contributors are listed below:

Federal Agencies:
- Department of the Army
  - Corps of Engineers District, Philadelphia
- Department of the Interior
  - Geological Survey
  - Fish and Wildlife Service

Interstate Agencies:
  Interstate Commission on the Delaware River Basin

State Agencies:
  New Jersey
    Department of Health
  New York
    Department of Health
  Pennsylvania
    Department of Health
  Delaware
    Water Pollution Commission

Municipal Agencies
  New York, New York
    Board of Water Supply
  Easton, Pennsylvania
    Bureau of Water
  Trenton, New Jersey
    Water Treatment Plant
  Philadelphia, Pennsylvania
    Water Department

SECTION II - INTRODUCTION

Hydrological Characteristics of Main Stream

4. Flow Patterns Figure 1 presents a plot of the various flow patterns of the Delaware River at Trenton, New Jersey which have been experienced in the past. The curvature of any flow frequency plot is a measure of the skewness of the distribution, i. e., the deviation from a normal distribution where 50% of the flow values are above and 50% below the average.

5. Minimum Flows Further inspection of Figure 1 provides a picture of the seasonal flow variation to be expected at Trenton. The minimum average 30 day flow which usually occurs during the months of August, September or October can be contrasted with the minimum average 120 day flow which usually covers the period from July through October. Hence, the 30 day period can be visualized as gradually increasing to the 120 day flow which gradually increases to the average annual flow. The decreasing curvature of the respective plots as the flow period is increased is indicative of the relative variation about the mean value. Therefore, on a 30 day basis, considerable more variation may be expected than on an annual average basis.

6. The interrelationship between each of the curves of Figure 1,and likewise between their relative frequencies of occurrence, is of importance in ultimately assessing the quality of a given stream. For example, the average minimum seven day flow is of interest in obtaining an instantaneous picture of the flow of the stream, but tends to be slightly "harsh" on the stream's recovery capacity. Also, when the seven day flow is used in subsequent analyses, it fails to take into account any seasonal, or long-term changes or industrial process variations. Hence, an integrated picture can be obtained only by examining all significant flow periods. The minimum average thirty day flow brackets monthly variations, whereas the minimum average 120 day flow encloses the usual low flow months and yet does not sacrifice the accuracy which annual averages lose, since

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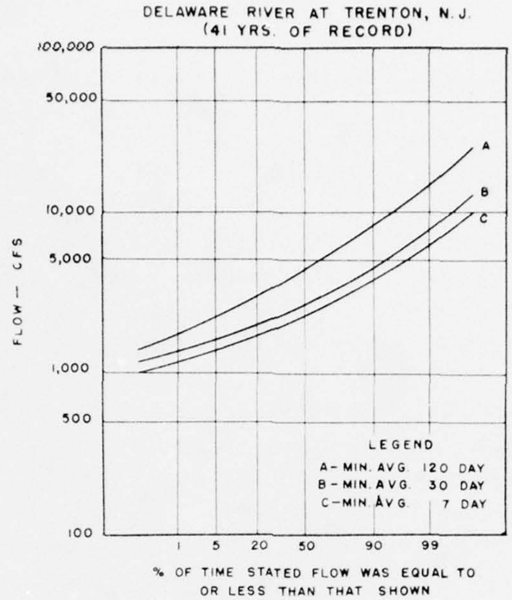

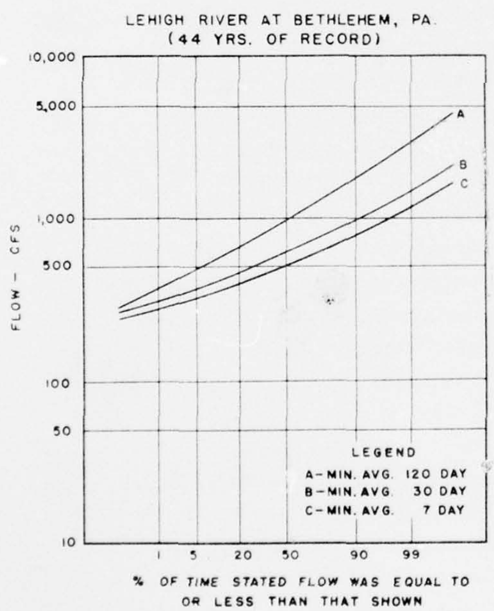

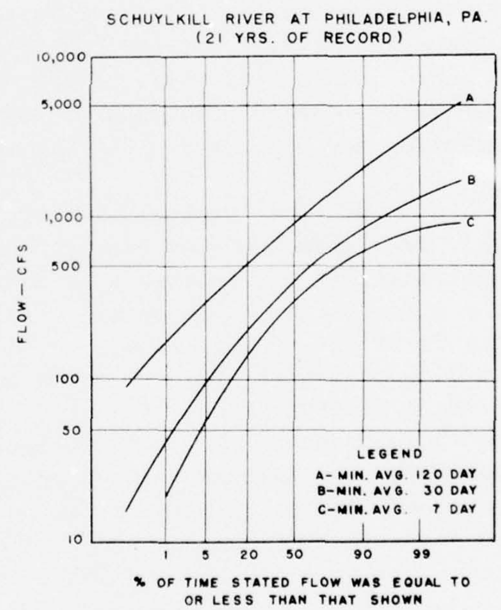

(DATA COURTESY OF CORPS OF ENGINEERS)

PART B — STREAM QUALITY

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FIGURE 1

LOW FLOW FREQUENCY CURVES

these latter means include high flow months which are of lesser interest in stream quality assessment.

7. Table 1 below tabulates the magnitudes of 7-, 30-, and 120 day low flows at Trenton for annual frequencies of 50-, 20-, 10-, and 5%. Recurrence intervals corresponding to these frequencies are indicated. The annual frequency is the "odds" or per cent chance of occurence in any given year that the low flow associated with the indicated flow period will be equal to or less than the stated flow. Thus the 7-day low flow at Trenton would be expected to have a 10% chance of being equal to or less than 1560 cfs. Stated in terms of the recurrence interval, the 7-day low flow at Trenton would be expected to be as low or lower than 1560 cfs on the average once in ten years.

TABLE 1

FREQUENCY OF OCCURRENCE OF VARIOUS FLOW PERIODS
Delaware River at Trenton, New Jersey
(Cubic Feet Per Second)
(Data Courtesy of Corps of Engineers)

Annual Frequency	Average Recurrence Interval	Minimum Average 7 Day	Minimum Average 30 Day	Minimum Average 120 Day
50%	Two years	2,260	2,670	4,420
20%	Five years	1,730	2,000	3,000
10%	Ten years	1,560	1,770	2,750
5%	Twenty years	1,400	1,600	2,250

8. Regulation In the past, the flows at Trenton and upstream at Port Jervis have been influenced by the Wallenpaupack power plant which is used principally for peak power purposes and may discharge from zero to 1,700 cfs during any 24 hour period, and the Mongaup River power plant and reservoir which may discharge as much as 750 cfs during a day. At Trenton these regulation do not tend to decrease the minimum average one day flow (since the respective watersheds controlled are relatively minor), but rather the regulations tend to increase low flows when they do occur.

9. Considerably more important than the Wallenpaupack and Mongaup reservoirs are those presently being used for the New York City water supply system. These include the Neversink and Pepacton reservoirs as well as the Cannonsville reservoir now under construction. Under a Supreme Court decree, New York City is presently required to maintain a basic minimum rate of 1,525 cfs at Montague, New Jersey (Milford, Pa.) and upon completion of the Cannonsville reservoir will be required to maintain a basic minimum rate of 1,750 cfs. Since only two of these reservoirs have been in operation for the past three to four years, the low flow frequency studies made on upstream tributaries tend to lose their significance. It is obvious that in maintaining a certain basic minimum rate the differences between the minimum average one day flows, the minimum average seven day flows and probably the minimum average thirty day flows will be considerably less than has been experienced in the past. However, these regulation will tend more to improve the low flow characteristics of the stream than to decrease the amount of flow available during drought periods. These New York City reservoirs have been and will be supplying additional releases from excess storage (storage not needed for diversions within the Decree allocation). These releases are sent between June 15 and March 15, in an effort to maintain a higher stage than that above the minimum at Montague for as long as excess storage remains available. This regulation operation is under the direction of a River Master designated in the Supreme Court Decree.

Hydrologic Characteristics of Two Major Tributaries

10. <u>Lehigh River</u> On an average monthly basis, this tributary contributes approximately 20% of the flow of the main stream at Riegelsville. The flow patterns of the Lehigh, therefore, are of importance in evaluating not only the quality of the Lehigh itself, but also its effect upon the main stream. Figure 1 is a plot the frequency of occurrence of various flow periods for the Lehigh River. It is seen that the curves are less concave than those of the main stream, thereby tending to be more normal. It should be recognized that a utilization of a minimum one day flow may lead to difficulty since the minimum day on the tributary may not necessarily occur on the same day as that on the main stream. In fact, in examining the period of flow records, in only two instances did the day of minimum flow on the Lehigh River coincide with the day of minimum flow on the Delaware River. Hence, in comparing the flows of the Lehigh and the Delaware, it is more pertinent to deal with 30 day flows and probably the 120 day flows in order to minimize the differences of time involved. On the basis of Figure 1, Lehigh River, Table 2 has been tabulated below.

TABLE 2

FREQUENCY OF OCCURRENCE OF VARIOUS FLOW PERIODS
Lehigh River at Bethlehem, Pennsylvania
(Cubic Feet Per Second)
(Data Courtesy of Corps of Engineers)

Annual Frequency	Recurrence Interval	Minimum Average 7 Day	Minimum Average 30 Day	Minimum Average 120 Day
50%	Two years	500	610	970
20%	Five years	390	470	670
10%	Ten years	350	410	560
5%	Twenty years	320	370	470

11. Schuylkill River The Schuylkill River is a major tributary discharging into the tidal portion of the Delaware River at Philadelphia, Pennsylvania. Figure 1 is a plot of the low flow frequencies determined from past records. When the flow pattern of the Schuylkill is compared to the flow pattern of the Delaware considerable differences are noted in the slope of the frequency curve for the Schuylkill. The steep slope is indicative of the relatively higher degree of regulation throughout the length of the Schuylkill. Table 3 tabulates the significant points of Figure 1, Schuylkill River.

TABLE 3

FREQUENCY OF OCCURRENCE OF VARIOUS FLOW PERIODS
Schuylkill River at Philadelphia, Pennsylvania (Fairmount Dam)
(Cubic Feet Per Second)
(Data Courtesy of Corps of Engineers)

Annual Frequency	Recurrence Interval	Minimum Average 7 Day	Minimum Average 30 Day	Minimum Average 120 Day
50%	Two years	304	400	908
20%	Five years	143	206	508
10%	Ten years	86	138	370
5%	Twenty years	54	95	280

Water Uses In Report Area

12. The waters of the Delaware River basin under consideration in this report are used for all water uses, including: municipal and industrial water supply, bathing, boating, fishing and hydropower. New York City upon completion of its construction program will divert up to a total of 800 million gallons per day (mgd) from the West and East Branches of the Delaware River and from the Neversink River. Hydropower facilities are located primarily in the upper portions of the basin. Recreational and resort facilities are extensive throughout the basin. Some of the larger users of the Delaware River for municipal water supply include Philadelphia and Easton, Pa. and Trenton, N. J. In addition, many smaller communities draw on tributaries to supply their needs. Above Trenton, industrial water usage is concentrated mainly in the Allentown-Bethlehem and Easton-Phillipsburg areas. Below Trenton, the extensive industrialization of the area necessitates the use of large quantities of water for both process and cooling purposes. Water use in the basin is discussed at length in Part A of this Appendix.

SECTION III - STREAM QUALITY OF DELAWARE RIVER BASIN FROM HEADWATERS TO TRENTON, N. J.

Previous Studies

13. Data are routinely collected at a total of twenty stations in the New York section of the Delaware River headwaters by the New York City Board of Water Supply in connection with the operations of the New York City Delaware basin reservoirs. These data provide relatively long-term records on the Neversink River, the East and West Branches and the main stream. Figure 2 presents the locations of these routinely sampled stations.

14. In addition to the Board of Water Supply stations, the Pennsylvania Department of Commerce, State Planning Board, in cooperation with the U. S. Geological Survey and the Pennsylvania Department of Forests and Waters maintained a sampling station at Atco (Narrowsburg, New York) on the Delaware River from 1947 to 1951.[1] Composite samples were obtained from grab samples collected daily and over a ten day period, and then subsequently analysed. Analyses were performed primarily to determine chemical characteristics such as hardness, specific conductance etc.

15. In 1929 a water quality study was made of the Delaware River proper from Trenton, N. J. to Port Jervis, N. Y.[2] Some 248 samples were collected over a 2 1/2 month period beginning July 1, 1929. The results of this study are incorporated under Section III, Future Trends.

16. During 1946 a water quality study of the Delaware River was made with reference to the effect of water quality

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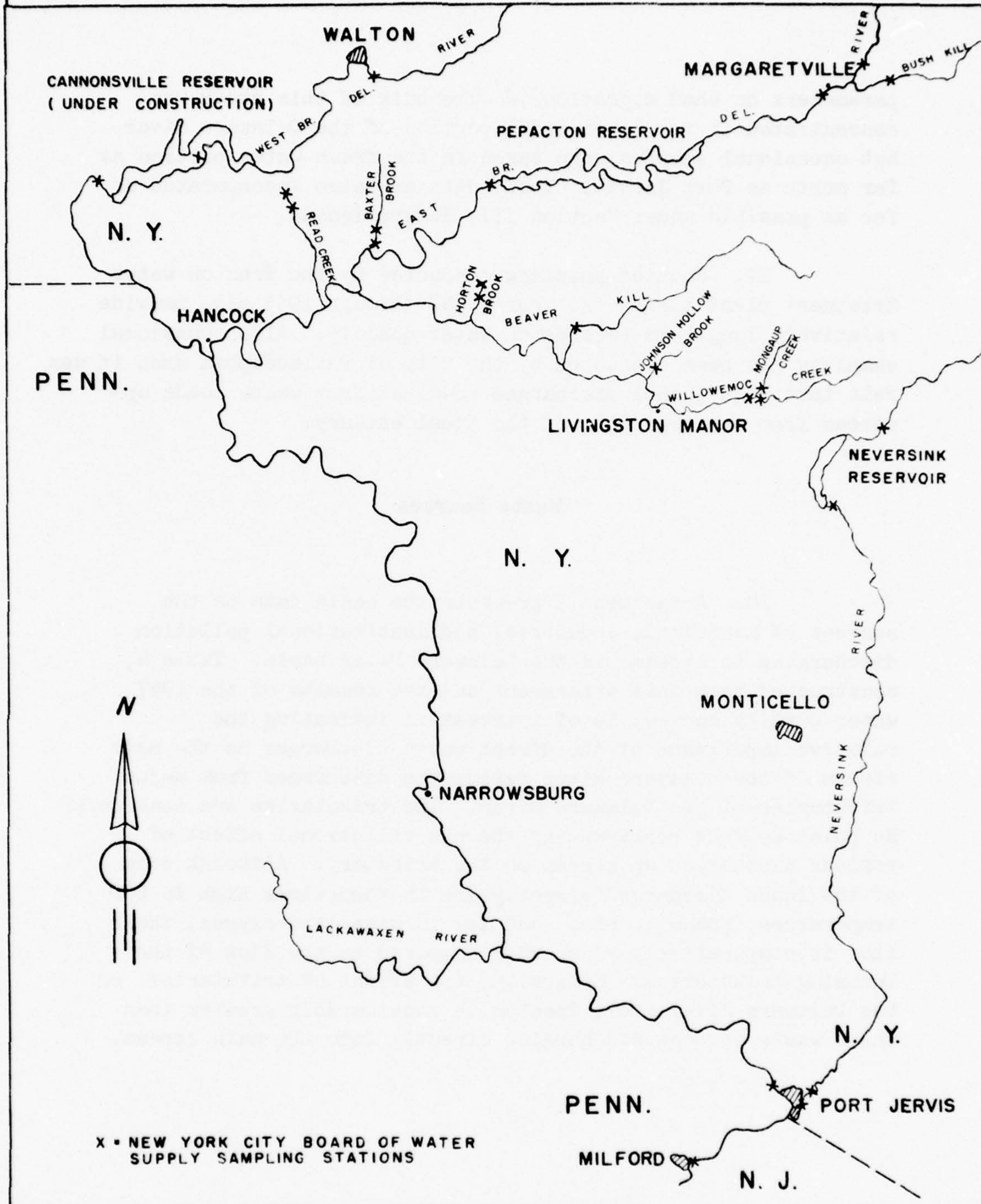
1/ This and the following footnotes refer to respectively numbered entries in the Bibliography at the end of the Appendix.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 2
LOCATION OF NEW YORK CITY BOARD OF WATER SUPPLY SAMPLING STATIONS

parameters on shad migrations.[3] The bulk of this study was concentrated in the lower tidal portion of the Delaware River but occasional samples were taken in the fresh water portion as far north as Port Jervis. These data are also incorporated as far as possible under Section III, Future Trends.

17. Routine sampling conducted by the Trenton water treatment plant during the years 1948 through 1955 also provide relatively long-term records on water quality. Also occasional sampling has been conducted by the City of Philadelphia when it was felt that high phenol discharges resulted from waste loads up-stream from the beginning of the tidal estuary.

Waste Sources

18. Attachment 1 presents the basic data on the sources of municipal, industrial and institutional pollution discharging to streams in the Delaware River basin. Table 4, constructed from this attachment and the results of the 1957 water quality survey, is of interest in indicating the relative importance of the direct waste discharges to the main stream of the Delaware River versus the discharges from major tributaries of the Delaware River. The tributaries are considered as point sources representing the net pollutional effect of various discharges up stream on the tributary. Although some of the loads discharged directly are in themselves high in BOD temperature, phenols, etc., and low in dissolved oxygen, their flow is comparatively minor when compared to the flow of the incoming tributaries. Generally, the effect of tributaries on the Delaware River above Trenton is considerably greater than those waste sources discharging directly into the main stream.

TABLE 4

BASIC DATA ON SIGNIFICANT WASTES
DISCHARGED DIRECTLY TO THE DELAWARE RIVER
FROM PORT JERVIS, N.Y. TO TRENTON, N.J.

Name and Location	Type of Wastes	Waste Treatment Provided	Est. PE* Discharged	Remarks
Neversink River	-	-	16,700	
Plating Plant, Del. Water Gap, Pa.	Plating & Stripping	Lagoon Holding tanks Septic tank	DNA	Copper Cyanide Chromium Waste
Chemical Plant Belvedere, N.J.	Organic Chemicals, Sanitary	Secondary for Sanitary	DNA	Mainly Cooling Water
Chemical Co. Phillipsburg, N.J.	Organic Chemicals	None	12,000	Also phenol waste
Lehigh River	-	-	88,500	
Easton, Pa.	Municipal	Secondary	1,700	
Phillipsburg, N.J.	Municipal	Secondary	500	
Paper Co. Riegelsville, N.J.	Paper	None	7,000	Also phenol waste
Musconetcong River	-	-	9,200	
Paper Co. Milford, N.J.	Paper	Savealls	20,000	
Lambertville, N.J.	Municipal	Secondary	100	
Paper Co. New Hope, Pa.	Paper	Secondary	4,000	

*PE on basis of 0.17 lbs. of 5 day BOD per person per day
DNA - Does not apply

Survey of July and August 1957

19. Period of Survey During the months of July and August, 1957, the U. S. Public Health Service, in cooperation with the States of Pennsylvania and New Jersey, conducted an extensive water quality survey, commencing on July 8, 1957.

20. Sampling stations A total of 19 stations were occupied for varying periods during the survey. The location and description of each of these stations is indicated in Figure 3 and Table 5.

21. Stream sampling and analysis procedures All samples were analyzed according to the procedures outlined in "Standard Methods for the Examination of Water, Sewage and Industrial Wastes, 10th Edition." At all stations the dissolved oxygen (DO) concentration and the temperature were measured at the time of sampling. Five day biochemical oxygen demand (BOD) determinations were made from composite samples collected at all stations. Due to the physical limitations imposed upon the survey, data for determining the deoxygenation rate constants were determined only at Port Jervis (#2), Easton (#10), Raubsville (#12), Milford (#14), and Yardley (#19) on the main stream, and Brodhead Creek (#6) Lehigh River (#11), and the Musconetcong River (#13). The tests for BOD, pH, turbidity, alkalinity, hardness and coliform organisms were determined on samples brought into the Easton Water Plant laboratory by the field crews, where the analyses were performed by a chemist especially assigned from the Robert A. Taft Sanitary Engineering Center of the Public Health Service. The tests for phenols, cyanides, tastes and odors, and iron were determined by the personnel of the Torresdale Water plant on samples taken to the Philadelphia Water Works. All samples were packed in ice by the field crews until delivered to the respective laboratories for analysis. Wherever practical, samples were taken from the right quarter, mid-stream and the left quarter. For some tributaries, it was not feasible to quarter-section the stream, and only one sample was taken at the mid-point. Water depths were determined at the time of sampling and the water samples were taken according to the following schedule:

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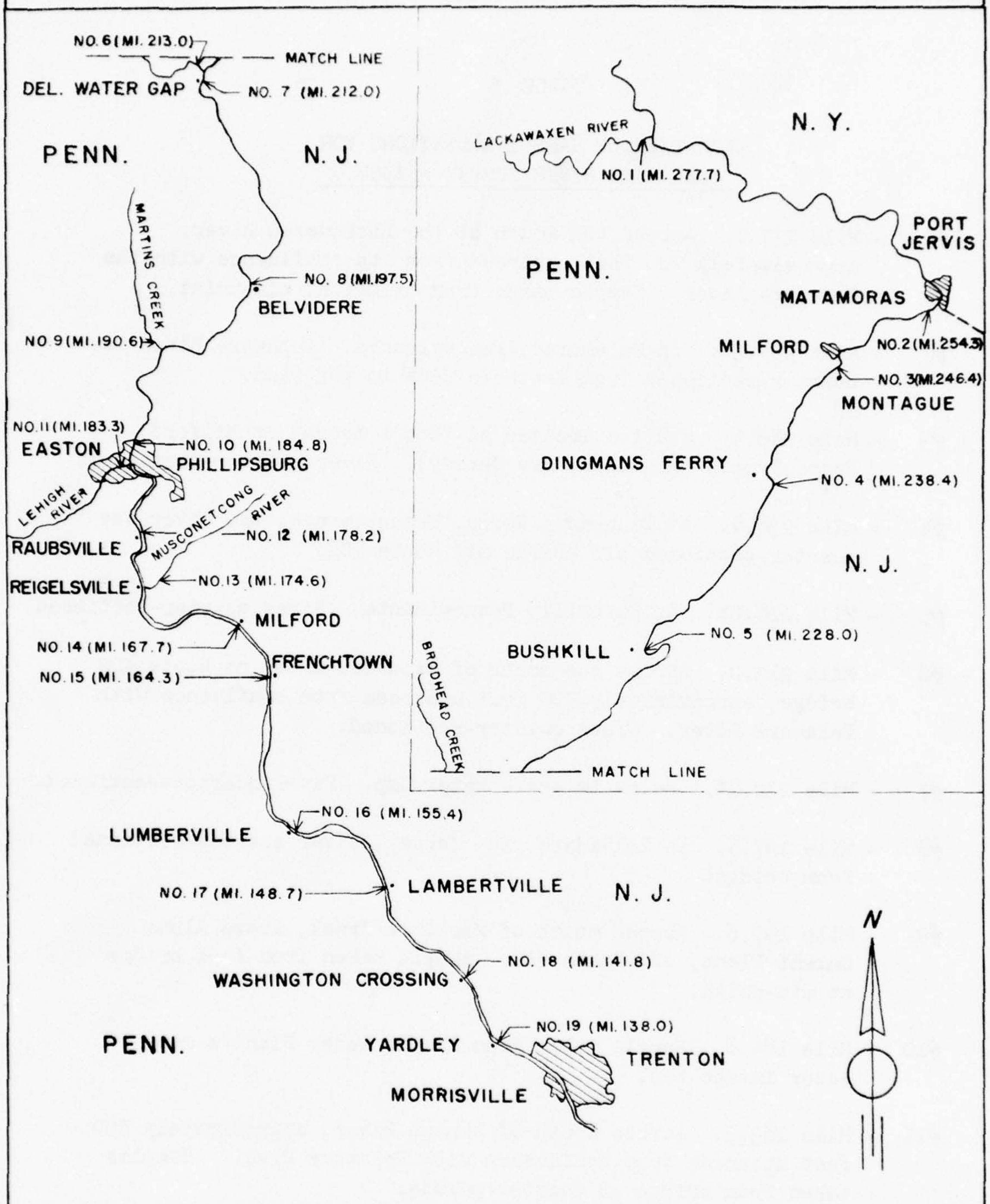


PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 3

LOCATION OF SAMPLING STATIONS

SURVEY OF JULY AND AUGUST – 1957

TABLE 5

LOCATION OF SAMPLING STATIONS FOR
DELAWARE RIVER SURVEY - 1957

#1 - Mile 277.7. Across the mouth of the Lackawaxen River, approximately 700 feet upstream from its confluence with the Delaware River. Sample taken from bridge at mid-point.

#2 - Mile 254.3±. In Matamoras, Pennsylvania. Delaware River was quarter-sectioned from Foster's dock to far side.

#3 - Mile 246.4. Station located at "Bob's Beach" at Milford, Pennsylvania (Montague, New Jersey). River quarter-sectioned.

#4 - Mile 238.4. At Dingman's Ferry, Pennsylvania, the River was quarter-sectioned off bridge off Route 209.

#5 - Mile 228.0±. At Bushkill, Pennsylvania. River quarter-sectioned.

#6 - Mile 213.0. Across the mouth of Brodhead Creek on Route 402 bridge, approximately 300 feet upstream from confluence with Delaware River. Creek quarter-sectioned.

#7 - Mile 212.0±. Below Delaware Water Gap. River quarter-sectioned.

#8 - Mile 197.5. In Belvidere, New Jersey, River quarter-sectioned from bridge.

#9 - Mile 190.6. Across mouth of Martin's Creek, above Alpha Cement Plant, off Route 611. Sample taken from foot bridge at mid-point.

#10 - Mile 184.8. Sample taken from Easton Water Plant's raw water intake tap.

#11 - Mile 183.3. Across mouth of Lehigh River, approximately 500 feet upstream from confluence with Delaware River. Samples taken from bridge at quarter-points.

#12 - Mile 178.2±. (a) In Raubsville, Pennsylvania. River quarter-sectioned from dock to far side. (b) One sample also taken at mid-point from Delaware Canal in Raubsville.

TABLE 5 (Continued)

LOCATION OF SAMPLING STATIONS FOR
DELAWARE RIVER SURVEY - 1957

#13 - Mile 174.6. Across mouth of Musconetcong River, approximately 50 feet upstream from its confluence with Delaware River. Sample taken at mid-point from foot bridge of Riegel Paper Company at Riegelsville, New Jersey.

#14 - Mile 167.7. (a) In Milford, New Jersey, samples taken from bridge at quarter-points. (b) One sample also taken from bridge at mid-point from Delaware Canal.

#15 - Mile 164.3. In Frenchtown, New Jersey, samples taken from bridge at quarter-points.

#16 - Mile 155.4. In Lumberville, Pennsylvania, samples taken from foot bridge at quarter-points.

#17 - Mile 148.7. (a) In Lambertville, New Jersey, samples taken from Route 202 bridge at quarter-points. (b) One sample also taken at mid-point from Delaware Canal.

#18 - Mile 141.8. In Washington Crossing, New Jersey and Pennsylvania, samples taken from Route 532 bridge at quarter-points.

#19 - Mile 138.0. In Yardley, Pennsylvania, samples taken from bridge at four points; right, middle right, middle, and middle left. Far left bay was excluded.

(a) for depths between 5 and 15 feet, inclusive, the samples were taken at approximately 0.2 of the depth below the water surface,

(b) for depths over 15 feet, samples were taken at 0.2 and 0.8 of the depth below the water surface, and

(c) for depths under 5 feet, the samples were taken at approximately mid-depth.

22. Industrial waste sampling procedures Industrial water use data were obtained and industrial waste sampling was performed separately in the two States of New Jersey and Pennsylvania. The field work in Pennsylvania was performed by personnel from the Pennsylvania Department of Health under the supervision of personnel from the Public Health Service. Field work in New Jersey was performed by Public Health Service crews. Discussions were held with plant officials to determine the nature of the process involved, purity of water required, number of employees and estimated volume of production. Depending upon the industry sampled, analyses were made of the effluents from various units within the plant, and also of the total plant effluent discharged to the stream.

23. Climate during survey The summer survey was conducted during a period of low precipitation, high temperatures, and relatively low wind velocities. During the month of July a total of only 1.23 inches of rain was measured at Trenton. During the month of August, a total of 1.10 inches was measured. These values represent, respectively, 2.83 inches and 3.49 inches below the normal for these months. During July 1957, there were twelve days during which the average air temperature was 90° F. or above, the average temperature for the month being 76.7°F. During August 1957, the temperature was slightly cooler, averaging 72.1°F. The average hourly wind speed as measured at Trenton was 8.4 miles per hour during July and 7.5 miles per hour during August.

24. Main stream flows during survey The average flow at Trenton for the month of July 1957 was 2,907 cfs and for the month of August 1957 was 2,018 cfs. These flows occurred with frequencies of 60% and 20% respectively of past **minimum monthly average flows** (see Figure 1). Precent frequency indicates the percent of time that the flow was equal to or less than the stated flow. For example, 20% frequency indicates that during the month of August 1957, for a flow of 2,018 cfs, past records of minimum average monthly flows at Trenton have shown that the August flow was exceeded 80% of the time. Only 20% of the time was it equal to or less than 2,018 cfs. Actually, during the entire period of the survey, the fluctuation in the flow was relatively minor. A range of only 1,000 cfs was experienced during the period of survey in July and August. The days of minimum flow in the Delaware River during the period of survey occurred on both August 21 and 23, when 1,650 cfs was measured. The lowest seven day flow was 1,697 cfs, which occurred from August 19 to August 25, inclusive, and represents a frequency of 16%. In general, the flows of the Delaware River during the survey months were relatively low, on the basis of previous records. Indeed, the frequencies are more significant (due to the utilization of minimum criteria in preparing frequencies of occurrence) than if average figures had been used.

25. Tributary flows during survey The average flows for the Lehigh River at Bethlehem, Pennsylvania, for the months of July and August 1957 were 629 **cfs** and 442 cfs, respectively. These flows represent a frequency of occurrence on a minimum average monthly basis of 53% and 14%. In other words, of past flow records for the Lehigh River, once in every 7 years 442 cfs was the lowest average flow that persisted for 30 days. The minimum day occurred on August 24 when 388 cfs was recorded. This represents a frequency of 21%. Likewise, the minimum average seven day flow during the period of survey was 395 cfs from August 19 through August 25. This represents a frequency of occurrence of 19%. In general, then, the survey was conducted during a period when the flow in the Lehigh River was relatively low on the basis of the above mentioned frequencies.

Results of Survey

26. In a strict sense, the results obtained from the survey present only a picture of the various water quality parameters as they existed under the conditions prevailing during the survey. The various measures of the water quality of any particular river may vary considerably from hour to hour, day to day, and season to season. The effect then of various man-made discharges can only be measured accurately over a long period of time whereby the various fluctuations can be observed. Hence, the actual results obtained from the analyses of the waters of the Delaware River should not be construed as being typical for other than those which occurred during the survey. This is not to infer that the survey results are insufficient to evaluate water quality conditions in the Delaware River. The analysis and interpretation of the results obtained provide a qualitative picture of the water quality of the River. In some cases, definite correlations were realized, utilizing available long-term data in order to quantitatively establish the significance of the water quality parameters.

27. <u>Biochemical oxygen demand</u> Table 6 summarizes the average biochemical oxygen demand concentrations as measured at each station. It is seen that in the area north of Easton, the BOD remained substantially constant, decreasing only slightly toward Easton. Below Easton, the BOD increased rapidly, with maximums experienced at the lower downstream stations. On July 15, the peak BOD's were obtained at all downstream stations. The survey maximum of 4.5 ppm was observed at Washington Crossing (#18) on that date.

28. <u>Dissolved oxygen</u> Examining the results obtained during the July and August survey as tabulated in Table 6, the dissolved oxygen content of the stream is relatively good. The only evidence of any oxygen "sag" is in the vicinity of Milford, New Jersey, where the average minimum dissolved

oxygen content dropped to as low as 6.9 ppm. The average minimum dissolved oxygen represents the mean of the lowest values obtained during each day of sampling at each particular station. The dissolved oxygen content of the Delaware River above Easton at no time fell below 7.0 ppm or 83% of saturation.

29. Figure 4 is a plot of the average minimum and the average dissolved oxygen content in ppm against river miles. It is seen that the DO concentration increased quite sharply below Milford, New Jersey (although the BOD increased) which is presumably due to the self-purification capacity and the algal activity of the stream in this reach. The magnitude of the dissolved oxygen content (83% to 121% of saturation) in the stretch above Easton, precludes any definite correlation of the DO content with the waste loads.

30. Stratification With respect to vertical and lateral stratification, the River in general evidenced a marked degree of homogeneity at almost every cross-section, as can be seen by an examination of the dissolved oxygen values as measured across the River at the quarter points (see Figure 5). Due to the relatively shallow depths, little to no vertical stratification should be expected. However, this may not apply under different flow regimens. The survey was conducted during a period of extreme low flows, and consequently, shallow depths. Although some lateral stratification might be expected in the broader stretches of the River around the vicinity of Milford, New Jersey (#14) to Yardley (#19), no significant degree of stratification was observed. As was indicated previously in this report loads discharged directly to the Delaware River are of relatively minor importance, since practically all major loads come from tributaries. Since little stratification was observed adequate mixing of these loads with the main stream can safely be assumed.

31. Algal effects. Considerable visual evidence of algal blooms were seen in the stretch of the river from Easton to Port Jervis. Large algal growths were also visually observed in the vicinity of Washington Crossing. In order to more fully evaluate the diurnal fluctuation due to algal photosynthesis, samples were taken at 1 1/2 hour intervals through a complete

TABLE 6

SUMMARY OF RESULTS OF SURVEY
July and August, 1957

Station	No.*	5 Day BOD Average (ppm)	Hardness Average (ppm)	Alkalinity Average (ppm)	Turbidity Average (ppm)	Line No.
#2-Below Port Jervis, N.Y.	5	1.4	20	16	2	1
#3-Milford, Pa.	4	1.6	21	16	5	2
#4-Dingmans Ferry, Pa.	3	1.0	22	15	4	3
#5-Bushkill, Pa.	4	1.2	21	16	3	4
#7-Del.Water Gap, Pa.	5	1.3	23	18	3	5
#8-Belvidere, N. J.	4	0.8	26	20	5	6
#10-Easton, Pa.	6	0.5	38	30	3	7
#12-Raubsville, Pa.	10	1.9	59	42	6	8
#14-Milford, N. J.	9	2.1	66	47	7	9
#15-Frenchtown, N. J.	9	2.2	65	47	9	10
#16-Lumberville, Pa.	7	2.6	69	47	10	11
#17-Lambertville, N. J.	8	2.9	69	46	11	12
#18-Wash.Crossing, N.J.	8	2.7	71	48	10	13
#19-Yardley, Pa.	8	3.0	69	49	12	14
Tributaries						
#6-Brodhead Creek	6	2.8	40	24	8	15
#9-Martins Creek	5	1.3	135	53	6	16
#11-Lehigh River	10	3.6	132	86	8	17
#13-Musconetcong River	9	3.9	145	118	16	18

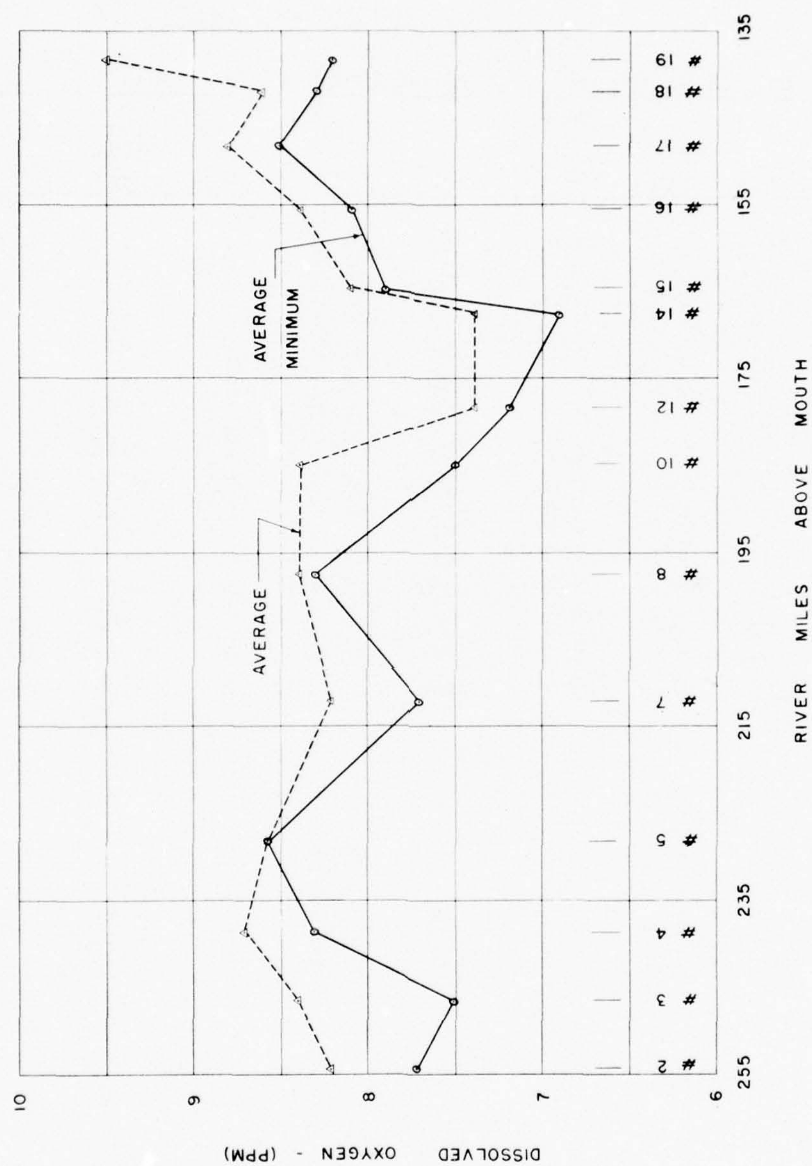
* Number of samples analyzed
** Individual determinations in parts per billion (ppb)

TABLE 6 (CONT.)

SUMMARY OF RESULTS OF SURVEY
July and August, 1957

Line No.	Dissolved Oxygen No.*	Dissolved Oxygen Avg. (ppm)	Dissolved Oxygen Avg. Min. (ppm)	Temperature No.*	Temperature Avg. (°C)	Iron No.*	Iron Avg. (ppm)	Phenols (ppb)**
1	57	8.2	7.7	57	23.7	-	-	-
2	48	8.4	7.5	48	24.5	-	-	-
3	56	8.7	8.3	56	22.1	-	-	-
4	11	8.6	8.6	12	22.8	-	-	-
5	94	8.2	7.7	96	24.2	-	-	-
6	12	8.4	8.3	12	24.5	-	-	-
7	29	8.4	7.5	29	25.5	1	0.16	0
8	120	7.4	7.2	120	25.9	4	0.39	12, 1, 0, 19
9	125	7.4	6.9	126	25.5	4	0.19	12, 4, 0, 10
10	27	8.1	7.9	27	24.1	2	0.22	8, 2
11	23	8.4	8.1	23	25.4	3	0.25	8, 0, 4
12	23	8.8	8.5	23	26.1	1	0.15	3, 30
13	69	8.6	8.3	69	25.6	3	0.17	21, 30, 1, 18
14	128	9.5	8.2	128	25.9	3	0.19	1, 12, 0, 21
15	24	9.2	9.0	24	22.4	-	-	-
16	5	8.6	-	5	19.4	-	-	-
17	135	5.9	5.4	135	26.6	2	0.34	-
18	113	5.9	5.5	113	21.5	4	0.38	-

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 4

DISSOLVED OXYGEN PROFILE

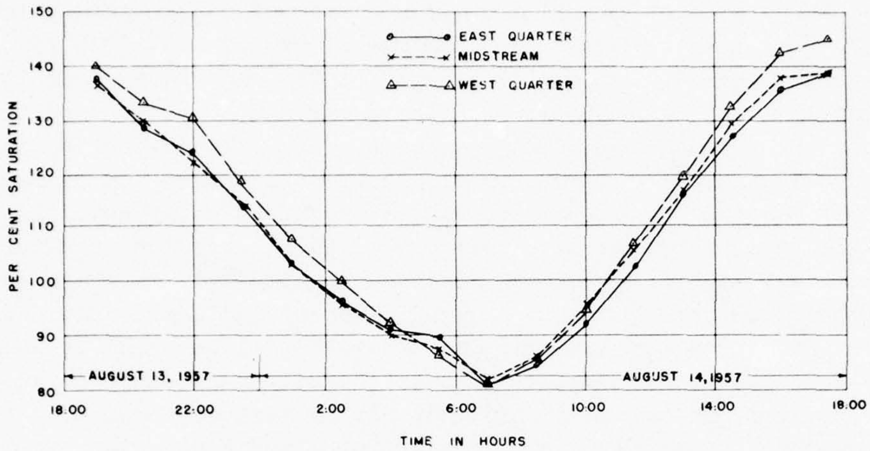
SURVEY OF JULY AND AUGUST - 1957

22-hour period at Dingmans Ferry (#4) and at Washington Crossing (#18). The results obtained are plotted in Figure 5. The results for the Dingmans Ferry station showed a minimum dissolved oxygen saturation of about 84% (8.2 ppm) at 0830 and a maximum of nearly 115% (9.9 ppm) at 1730. During the 22-hour period covered at Dingmans Ferry from 1930 on August 12 to 1730 on August 13, almost maximum sunshine conditions occurred. Sunshine measured at Trenton by the U. S. Weather Bureau for August 13 indicated that a total amount of 13 hours and 51 minutes, or 100% of possible sunshine occurred on that particular day. However, on the August 12 sampling day, only 53% of possible sunshine occurred. The relatively smaller amount of sunshine on August 12 may have decreased the 0100 peak shown in Figure 5. Under maximum conditions of sunshine, this peak may have increased slightly since algae in general tend to increase oxygen production under conditions of increasing light. However, it can be stated that almost maximum conditions for the measure of the activity of the algae occurred during the sampling. It may be concluded that for the particular day on which the diurnal fluctuation was measured, the dissolved oxygen content contributed by the algae was significant and explains the relatively high DO contents obtained in the upstream areas. At the Washington Crossing station a low of 81% (8.0 ppm) at 0700 on the morning of August 14 and a high of 145% saturation (12.3 ppm) at 1730 on August 14 were observed. The wider fluctuation at Washington Crossing tends to indicate a relatively greater concentration of algae. Available sunshine on the days of sampling at Washington Crossing (August 13 and 14) ranged from 100% possible on August 13 to 91% possible on August 14. Hence, the diurnal fluctuations were measured under optimum environmental conditions for algal photosynthesis.

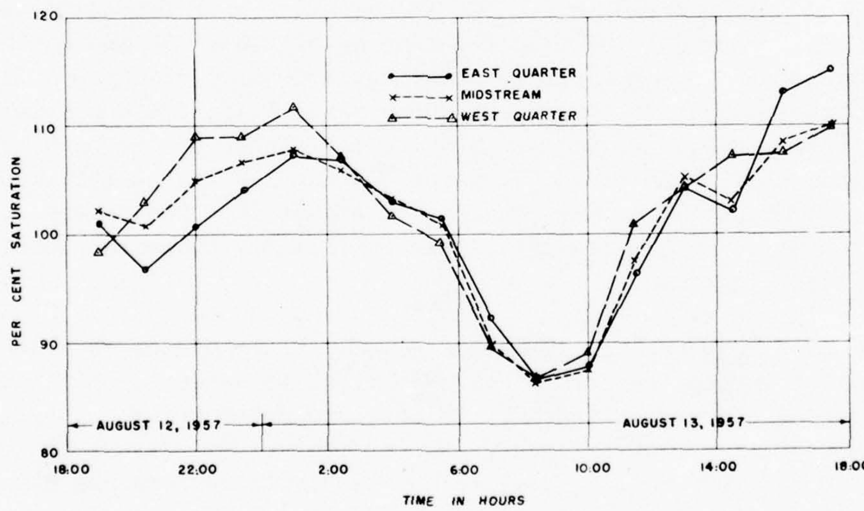
32. Temperature The average water temperatures obtained at each station during the survey are summarized in Table 6. For the entire period of survey, the average water temperature at Raubsville was 25.9°C. with a peak daily average temperature on July 22 of 29.2°C. Downstream from Raubsville the temperatures remained at approximately the same level (25.5°C to 27.2°C). The mean temperature for the stretch from Raubsville to Yardley including all temperatures recorded was 25.9°C. This included a range from 23°C to 30°C. The maximum average temperature occurred at the entrance of the Lehigh River and as indicated in Table 6 was equal to 26.6°C. Upon calibrat-

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN

DISSOLVED OXYGEN SATURATION AT WASHINGTON'S CROSSING, PA. AND N.J.



DISSOLVED OXYGEN SATURATION AT DINGMAN'S FERRY PA.



PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 5

EFFECT OF ALGAL CONCENTRATION ON DISSOLVED OXYGEN

SURVEY OF JULY AND AUGUST - 1957

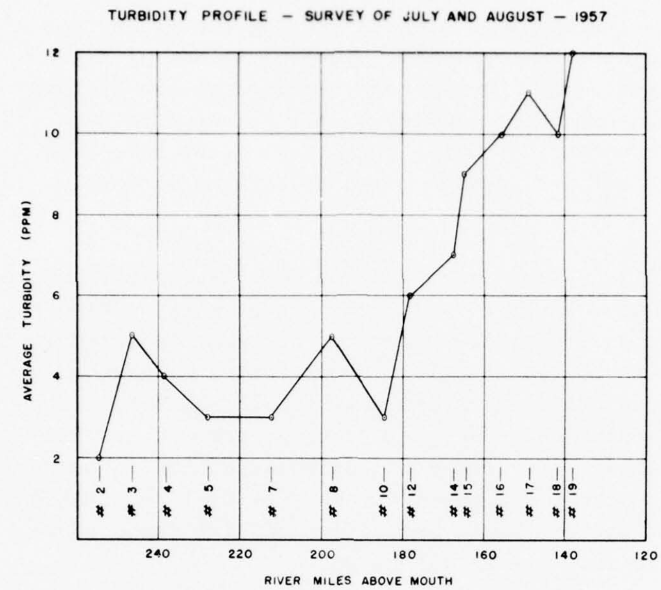
ing the various thermometers used during the survey, it was noted that a significant variation occurred in one of the thermometers used. This thermometer was used at the Milford (#14) and Frenchtown (#15) stations. All temperature data obtained at these stations using this thermometer have been deleted and are not included in any computations in this report.

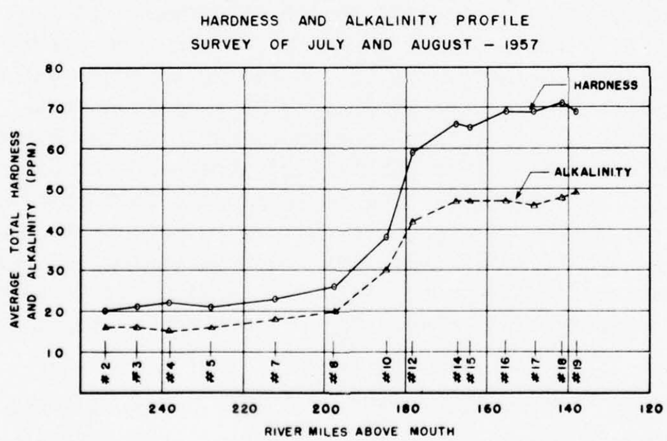
33. Little or no vertical and lateral stratification of water temperatures was noticed during the survey. With respect to the time of day, low water temperatures occurred in the early morning hours, reaching a peak in the afternoon. In general, the average water temperatures lagged behind the average air temperatures. In the vicinity from Lumberville to Yardley, average water temperatures equalled and in some cases exceeded average air temperatures. As will be pointed out later, this appears to be indicative of high temperature waste discharges into the Lehigh River.

34. Hardness and alkalinity Figure 6 and Table 6 indicate the average total hardness and alkalinity in ppm as measured at each station during the period of survey. It is seen that a sharp increase occurred in the stretch from Belvidere (#8) downstream to Yardley (#19). A fairly constant value is noted from Milford, N. J. to Yardley, with a maximum value of 71 ppm at Washington Crossing. For the stretch of the River from Easton (#16) north to Port Jervis (#2), the hardness concentrations also remained fairly constant, ranging from approximately 20 ppm to 27 ppm. The greatest hardness concentrations were observed in the tributaries reflecting both geological conditions and high hardness bearing waste discharges. It is seen that the total average alkalinity follows the hardness curve very closely.

35. Iron During the period of survey, several total iron concentration analyses were made on samples from each station between Easton (#10) and Yardley (#19). Maximum concentrations were noted at the Raubsville (#12) station where a peak value of 0.50 ppm was obtained on August 29, 1957. The iron concentrations downstream from Raubsville decreased gradually with occasional peaks of 0.30 to 0.35 ppm.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN





PART B — STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 6
TURBIDITY AND HARDNESS AND ALKALINITY PROFILES

36. Turbidity. Figure 6 and Table 6 indicate the average turbidity measured at each station during the survey. Again, the Delaware River north of Easton (#10) exhibited low and relatively constant turbidity values. However, turbidity in the reach of the River downstream from Easton as shown in Figure 6, rose sharply, reaching a peak at Yardley. The average at this station for the period of survey was 12 ppm, with a maximum of 16 ppm on July 19, 1957.

37. Phenols, and tastes and odors. During the summer survey, phenol determinations were made at all stations from Easton to Yardley. The results are tabulated in Table 6. Averaging the individual determinations has little practical meaning and all the results which were obtained are presented in Table 6. Maximum values of approximately 0.030 ppm, associated with a medicinal taste, occured at Lambertville (#17) and Washington Crossing (#18).

38. Taste and odor determinations were made on all stations from Easton downstream. Since these determinations are susceptible to personal influences, depending on the analyzer, only a qualitative and general description of the taste and odor conditions in the River at the time of the survey can be made.

39. Coliform bacteria. With the availability of routinely collected data from the City of Easton and the New York City Board of Water Supply, it was decided to forego any extensive bacteriological sampling. A general discussion of the analysis of these data is presented under paragraph 72.

Analysis and Interpretation of Data

40. General discussion. In general, there are two types of waste discharges; (a) those which for all practical purposes maintain their individual characteristics as they progress downstream, and (b) those which are influenced by the physical chemical and biological factors of the stream. Examples of the former are some of the heavy metals, and of the latter, organic

matter and those elements which combine chemically with the residual compounds in the stream. Depending upon local environmental conditions, certain stream quality characteristics, for example cyanides, phenols, etc., may be considerably more important, due to the industrial activity of the region. A stream suitable in all other respects may still be unfit for some uses due to the presence of these wastes.

41. The description of the various water quality parameters as they existed during the period of survey and the various interpretations which may be applied to these parameters requires the knowledge of various other intimately related factors:

(a) River flows and characteristics (which indicate time of flow, volume of dilution water available, and mixing factors involved)

(b) Biochemical oxygen demand concentrations (both in the river itself and any concentrations which are added)

(c) The rate at which the biochemical oxygen demand is satisfied.

(d) The rate at which oxygen is diffused into the stream by reaeration

(e) Temperature and its effects on (b), (c) and (d) and also per se

(f) Waste loads and locations related to the various other water quality parameters.

42. Time of flow Aside from a knowledge of the river flows occurring during the time of the survey which is of importance in determining at what point in the flow regime the sampling was conducted, it is also necessary to obtain information on the velocity of the river between any two stations. With reasonably accurate velocities determined and the distance between stations known, the time of flow can be calculated. The results obtained

are essential in estimating the rate of satisfaction of the biochemical oxygen demand and the rate at which dissolved oxygen is diffused into the stream. Calculations using Manning's formula indicated the results shown in Table 7. These times represent the average mass transit time of flow for the conditions prevailing during July and August, 1957. The times do not represent the movement of the river wave and hence differ from the times given in Appendix M, Hydrology.

43. Should any considerable physical change be imparted upon the Delaware, these results may not necessarily apply. The survey was conducted during a period of low flow with minor variations. At higher flows, the velocity picture may change considerably and the roughness coefficients which were calculated may no longer be valid. For the section of the Delaware River north of Easton, the determination of the time of flow is not as critical as in the lower stretch. This is due to the more uniform water quality character of the River in the upper reaches where only an overall qualitative picture can be obtained. This will be discussed more completely in the paragraphs to follow.

44. Biochemical oxygen demand. The addition of organic loads to the Delaware River has been discussed previously. Fully as important as determining the amount of the load is the net effect any addition has on the biochemical oxygen demand of the River itself. It should be emphasized that the BOD, except for rare instances, is not a pollutant in itself. High biochemical oxygen demand concentrations (10 - 12 ppm) in some cases tend to encourage the growth of slimes in industrial cooling lines. However, the primary interest in the BOD is that it may combine with other factors to lower the dissolved oxygen concentration of the stream. High BOD concentrations do not necessarily imply high coliform organism content. The rate of the utilization of oxygen to satisfy the demand imposed by the oxidizable material is the prime concern.

TABLE 7

TIME OF FLOW
(Survey of July and August, 1957)

Station	Slope (ft/1000')	Velocity (fps)	Stream Distance (miles)	Time (days)	Cumulative Time (days)
#10 - Easton, Pa.					
	.578	1.04	6.0	.35	.35
#12 - Raubsville, Pa.					
	.578	1.42	10.3	.44	.79
#14 - Milford, N. J.					
	.578	0.74	3.4	.28	1.07
#15 - Frenchtown, N. J.	.578	2.26	8.9	.24	1.31
#16 - Lumberville, Pa.					
	.578	1.30	6.7	.31	1.62
#17 - Lambertville, N. J.	.670	1.20	6.9	.35	1.97
#18 - Washington Crossing, N. J.					
	.430	1.62	3.8	.14	2.11
#19 - Yardley, Pa.					

45. Table 8 summarizes the data obtained on the long-term BOD sampling. Various mathematical analyses can be applied to these data in order to obtain the best rate of deoxygenation. For the purposes of this report, three different methods of obtaining the deoxygenation rate constants were used: a graphical method, the "Method of Moments", and an inventory of the ultimate biochemical oxygen demands introduced into the Delaware River between various points. In addition, for the stretch from Port Jervis to Easton, a semi-log plot of the average 5 day BoD in the stream versus the time of flow was employed. Table 9 summarizes the results obtained by these methods. It is seen that good agreement was obtained between the graphical method, the "Moment" method and the "inventory" method for the stretches to which they were applied. A low rate constant indicates that oxygen is being utilized at a lesser rate by the organism populations.

46. BOD records for past years are not available for any station in the stretch from Easton to Trenton. Hence, the loads obtained during the survey should be interpreted only as presenting a picture of conditions as they existed during the July and August, 1957 survey. With changing flows, loads and/or temperatures, the BOD load in the Delaware River may be significantly more or less than was obtained during the sampling program. However, if one considers the particular loads to remain constant for any given length of time, it can be said that the survey was conducted during a time when the effects of pollutional discharges were most severe, and the loads and deoxygenation rates as computed present a general representation of these conditions in the Delaware River.

47. At Milford, Pa. the BOD during 1950-1957 varied between 0.10 ppm and 1.5 ppm indicating the relatively minor effect of seasonal changes. The BOD content of the Delaware River above Port Jervis has averaged only 0.9 ppm for the years 1951 through 1957. Indeed, this average varies only slightly throughout the year and does not change appreciably even during the low-flow summer months. The July, August, and September averages

TABLE 8

LONG-TERM BIOCHEMICAL OXYGEN DEMAND
(Survey of July and August, 1957)
(Parts per Million)

Stations*	Days of Incubation 1	2	3	4	5	6	7	9	12	15	20
#2	0.2	0.3	0.4	0.5	0.7	0.7	0.9	1.0	1.3	1.6	1.9
#10	0.1	0.2	0.2	0.2	0.3	0.5	0.6	0.7	1.0	1.2	1.4
#10g	0.2	0.2	0.2	0.3	0.5	0.6	0.7	**	1.3	1.3	-
#12	0.5	1.0	1.3	1.6	2.0	2.4	2.8	3.4	4.0	4.4	4.8
#14	0.5	0.9	1.4	1.8	2.0	2.2	2.4	2.7	3.1	3.3	3.8
#19	0.8	1.3	1.9	2.5	2.7	2.9	3.2	3.6	4.9	5.1	6.7
Tributaries											
# 6	1.0	1.6	2.3	2.7	3.1	3.3	3.6	4.0	4.4	5.0	-
#11	0.7	1.1	1.6	2.2	3.2	4.1	5.0	5.8	7.0	7.4	-
#13	1.3	2.2	3.1	3.9	4.4	5.0	5.3	6.1	7.4	7.6	-

2 - Below Port Jervis, N. Y.

10 - Easton, Pa.

10g- " " (Grab)

12 - Raubsville, Pa.

14 - Milford, N. J.

19 - Yardley, Pa.

Tributaries

6 - Brodhead Creek

11 - Lehigh River

13 - Musconetcong River

* All samples composited unless otherwise noted.

** No nine (9) day analysis - ten (10) day analysis was 0.8.

TABLE 9

DEOXYGENATION RATES - k_1 @ 20° C.
(Survey of July and August, 1957)

Stations*	Graphical	Moment (1-7 days)	Moment (1-5 days)	Inventory
	Method of Computation			
# 2 - Below Port Jervis, N.Y.	.05	.04	.07	-
#10 - Easton, Pa.	.04	< .04	.18	.05
#10 - Easton, Pa. (grab)	.05	< .04	.06	
#12 - Raubsville, Pa.	.04	.04	.06	.05
#14 - Milford, N.J.	.07	.07	.06	.07
#19 - Yardley, Pa.	.04	.09	.08	.09
# 6 - Brodhead Creek	.08	.11	.11	
#11 - Lehigh River	.04	< .04	< .04	
#13 - Musconetcong River	.08	.09	.08	

* All samples composites unless otherwise noted.

for 1951-1957 averaged 1.0 ppm, an insignificant change. BOD values for the Neversink River below the Port Jervis sewage treatment plant have averaged 1.2 ppm since the start of plant operation. However, this produces only a minor change upon the BOD characteristic of the Delaware River.

48. Conclusions The area of the basin north of Easton is sparsely populated and in general contributes small amounts of organic pollution on an overall basis. Hence, the biochemical oxygen demand concentrations which are measured are due principally to "natural" pollution which exists in all streams due to decaying vegetable and other organic matter. In some local areas (downstream from small creameries or mills) comparatively high biochemical oxygen demand concentrations may be observed. However, examining the area as a whole, these conditions are minor and exert little influence upon the quality of the stream.

49. The magnitude of the biochemical oxygen demand concentrations observed in the Delaware River in the stretch from Easton to Trenton indicates that discharges which are capable of utilizing oxygen are added in significant amounts. Also, on the basis of both visual and quantitative observations, increased organic food matter is available in this reach of the River for utilization by such aquatic organisms as algae. The interpretation of the interrelationship of the biochemical oxygen demand and the DO of the River is discussed in paragraph 55.

50. Dissolved oxygen Unlike the biochemical oxygen demand concentration of a stream which can in itself be generally separated from the various other parameters, the dissolved oxygen concentration is intimately bound with a number of other factors: (1) the biochemical oxygen demand, (2) plants which tend to contribute dissolved oxygen through the process of photosynthesis (algae), (3) temperature which either increases or decreases the utlimate amount of dissolved oxygen which can be placed in solution (saturation value), (4) the physical characteristics of the stream, e. g., rapids, pools, stream velocities and (5) reaeration which involves a combination of all of the above.

51. In general, neither the biochemical oxygen demand nor the dissolved oxygen content of a stream are pollutants in themselves. The dissolved oxygen is primarily of interest only when it falls below certain limits, thereby inhibiting particular water uses. For example, various standards have been adopted, limiting the dissolved oxygen content of the stream to a minimum of 4.0 to 5.0 ppm. It is felt by some regulating agencies that this limit is necessary to maintain both a varied fish population and "healthy" stream biota. The stream is considered septic when the dissolved oxygen approaches complete depletion. This condition gives rise to obnoxious odors which impair the esthetic quality of the river.

52. Dissolved oxygen balanace. In presenting the dissolved oxygen resources of the Delaware River during the period of survey, the oxygen balance concept has been used. For any particular stretch, the dissolved oxygen content entering that stretch, plus the dissolved oxygen content of any tributary streams, plus the reaeration supplied to the river, minus the oxygen demand of the organic material, must equal the oxygen concentration leaving the particular stretch. Expressing this relationship as an equation, the following results:

Equation (i) $$DO_u + Do_t + DO_r - DO_{BOD} = DO_d$$

where DO_u = the total dissolved oxygen in lbs. per day at the upstream station

DO_t = the total dissolved oxygen in lbs. per day contributed by any tributaries

DO_r = the total dissolved oxygen in lbs. per day contributed by reaeration or other factors

DO_{BOD} = the total dissolved oxygen in lbs. per day utilized in the stabilization of the oxidizable organic matter

and DO_d = the total dissolved oxygen in lbs. per day at the downstream station

53. Table 10 summarizes the results of the DO balance computations. In an analysis of this type, the various assumptions which are made are of extreme importance in fully evaluating the results obtained. For example, it has been assumed that the rate of deoxygenation (or oxygen utilization) for the load at Raubsville remains constant and separate in flowing downstream to Milford. Likewise, the rate of deoxygenation of the biochemical oxygen demand contributed by the Musconetcong River has also been assumed to remain constant as it flows to Milford. That this is not exactly true is known, since the mixture of the wastes and the various mixing parameters of the stream may vary this assumption to some degree. Also, since average conditions have been used, the effect of any lateral or longitudinal mixing, as well as vertical stratification, has been neglected, which in the case of the Delaware River appears to be valid. The analysis also assumes that the entire amount of oxygen needed in the stabilization of the organic matter (5,700 lbs. per day) has been drawn from the oxygen "bank" of the stream itself. A portion of this amount may have been drawn from the oxygen content contributed by reaeration, which would tend to increase the 7,500 lbs per day. However, it is seen that the 7,500 lbs. per day, which is a result of reaeration and algal activity, represents the minimum amount under the particular conditions of the survey. In summary, the results presented in Table 10 are meaningful only so far as the qualifications surrounding the computations are taken into account. Variations may be expected from these results at other particular stream or environmental conditions.

54. Although data are not available on the dissolved oxygen contents of all of the tributary waters of the Basin north of Port Jervis, the low biochemical oxygen demand concentrations as discussed in paragraph 47 tend to indicate that the dissolved oxygen will be relatively high. Likewise, the lack of any significant continual sources of pollution also aids in the maintenance of good dissolved oxygen contents. Data collected on a weekly grab basis for the Neversink River above and below the Port Jervis sewage treatment plant outfall and for the

TABLE 10

AVERAGE DISSOLVED OXYGEN BALANCE
(Survey of July and August 1957)
(Pounds Per Day)

Station	DO_u At Upstream Station	DO_t From Tributaries	DO_{BOD} Total Utilized(*)	DO_d At Downstream Station	DO_r (**) Net Gain Or Loss
#10 - Easton, Pa.	91,000				
		15,800	1,600		+28,000
#12 - Raubsville, Pa.	133,200			133,200	
		1,000	5,700		+ 7,500
#14 - Milford, N. J.	136,000			136,000	
		Negligible	20,000		+30,000
#19 - Yardley, Pa.				146,000	

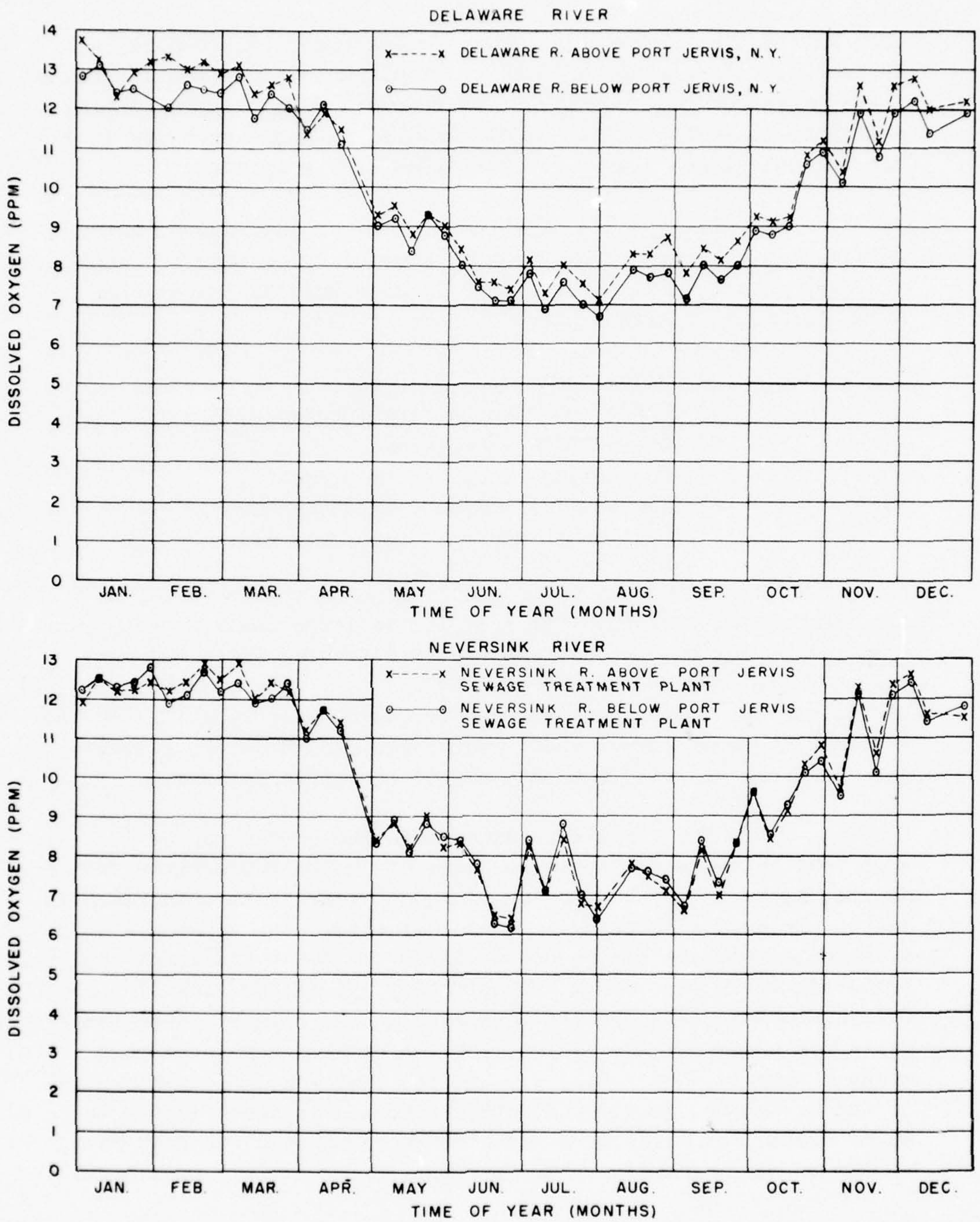
(*) Includes Dissolved Oxygen utilized in stabilization of organic matter contributed by significant tributaries.

(**) $DO_r = DO_d + DO_{BOD} - DO_t - DO_u$

Delaware River above and below the entrance of the Neversink River have been plotted in Figure 7. The typical seasonal variation is evident in both cases. For the Neversink River, it is seen that essentially there is no difference in the dissolved oxygen contents above and below the sewage treatment plant outfall since the amount of BOD added is relatively small. At no time did the DO fall below 6.0 ppm. For the Delaware River only a slight difference is noted above and below the entrance of the Neversink. Although there is increased dilution water available in the Delaware as opposed to the Neversink, the biochemical oxygen demand discharged by the Port Jervis sewage treatment plant does not actually have sufficient time to exert a demand before it enters the Delaware. A slight decrease in the dissolved oxygen contents is to be therefore expected.

55. Conclusions The results of the previous analyses of the data obtained during the summer survey indicate that in general the dissolved oxygen content of the Delaware River from Port Jervis to Trenton is relatively good. In order to present a more graphic picture of the dissolved oxygen content of the Delaware River in the vicinity of Milford, N. J. (the low point), one can assume that the desirable lower limit at this station is 5 ppm of dissolved oxygen which represents a total oxygen content of 91,500 lbs/day at a flow of 3,400 cfs. If all factors remain equal (except of course for the load which would tend to deplete the oxygen to the 5 ppm), a reserve of 44,500 lbs/day of oxygen is available under present conditions. In other words, if a waste load were introduced into the Delaware River and was of such magnitude so as to utilize 44,500 lbs/day of oxygen in the stretch from Raubsville to Milford the oxygen content at Milford may be depleted to as low as 5 ppm. This conclusion should be viewed as representing only a general magnitude. Indeed, should a sufficient waste load be introduced into the Delaware River between Raubsville and Milford to deplete the oxygen at Milford to 5ppm, the conditions in the stream may well be entirely different from those measured during the sampling survey. Should the waste be introduced upstream from

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



(DATA COURTESY OF NYC BOARD OF WATER SUPPLY)

PART B – STREAM QUALITY U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE	FIGURE 7 DISSOLVED OXYGEN SEASONAL VARIATION

from Raubsville, the surplus would be decreased considerably. In general, the stream is in a relatively good condition at the lowest measured point of dissolved oxygen and the oxygen surplus available is sufficient to allow for a significant increase in the biochemical oxygen demand concentration of the stream.

56. Temperature The temperature of any body of water is affected by a number of factors, some of which tend to increase the temperature, others which tend to decrease the temperature. Among the most important are:

(a) Solar radiation (increase)
(b) Radiation back-scatter (decrease)
(c) Evaporation (decrease)
(d) Conduction (increase or decrease)
(e) Convection (increase or decrease)
(f) High temperature waste discharges

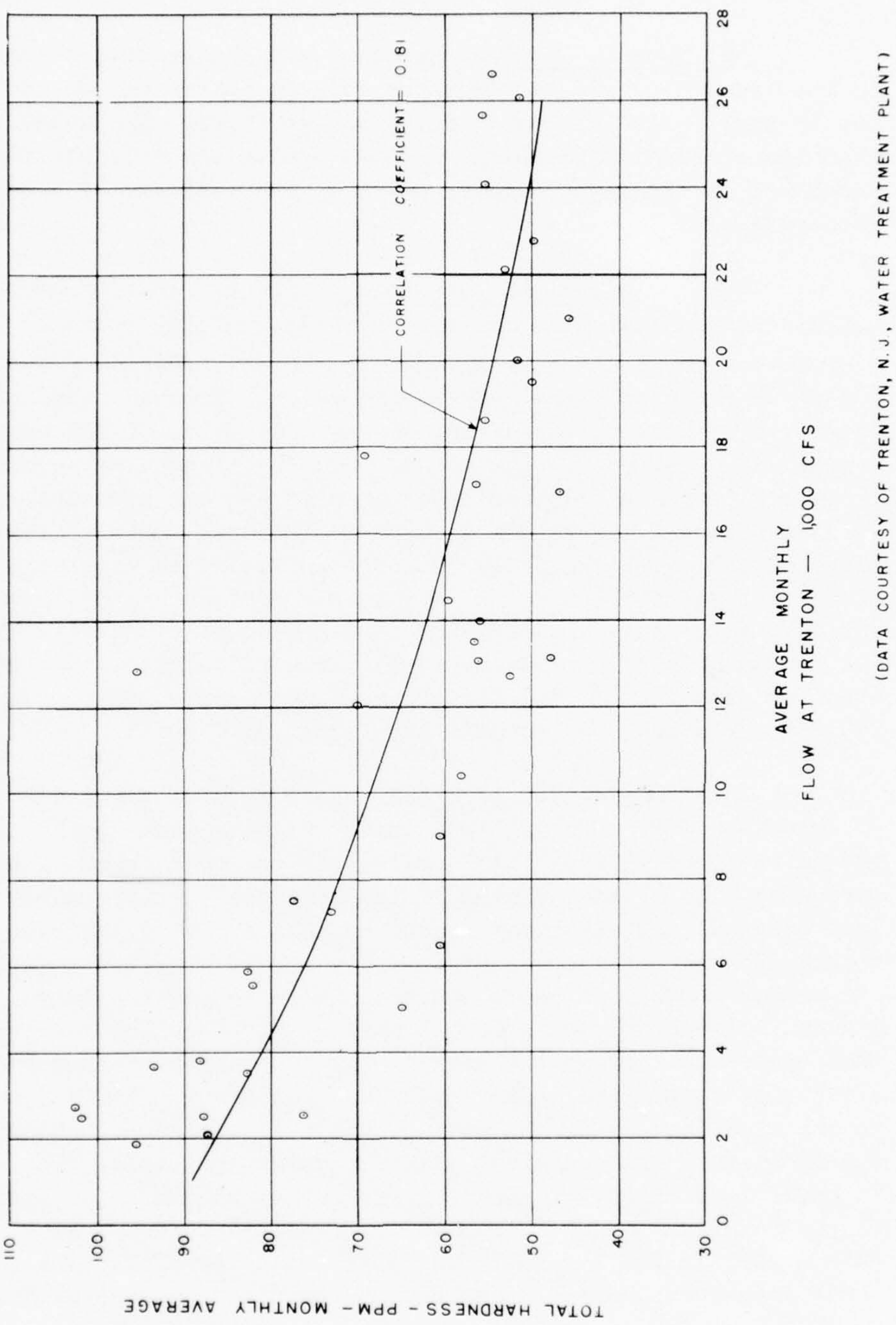
For a particular body of water one or more of the above may be the controlling factors. For example, in large shallow reservoirs, evaporation may be dominant whereas in a flowing river the man-made high temperature discharges may control. An accurate appraisal of the various temperature components can be made by utilizing the "balance" type of computation. This requires, however, extensive data in order to fully evaluate all of the above factors.

57. The results obtained from the summer survey indicate a general increase in the temperature of the Delaware River from Port Jervis, N. Y. to Trenton, N. J. Although some of this increase is due to the natural heating of a body of water, the relatively high average temperature of the Lehigh River of 26.6°C indicates that this tributary which represents approximately 25% of the flow of the Delaware may account for the increase in temperature. High temperature waste discharges to the Lehigh River at Bethlehem have reached maximum values of over 37.8°C. The peak daily average temperature of the Lehigh was 30.1°C indicating that the increase in the temperature at Bethlehem resulting from the high temperature discharges may persist as far as the confluence with the Delaware.

58. Conclusions It appears that the general increase in the temperature of the Delaware between Easton and Trenton is due in part to the entrance of the Lehigh River. The relatively high temperature of the Lehigh at the confluence reflects the discharge of high temperature wastes in the vicinity of Bethlehem, Pennsylvania.

59. Hardness and alkalinity From a domestic water supply viewpoint, a water with a hardness content in the vicinity of 50 ppm is considered to be "soft". Hardness over 100 ppm may require treatment of the water. From an industrial water use viewpoint, the desirable maximum limits of hardness in a water may vary from 0 ppm to over 200 ppm, depending upon the industrial process. Boiler feed water at extreme pressures requires hardness of very low values as do also laundry, textile, rayon and pulp industries. Alkalinity is not a pollutant in itself, but rather is indicative of high pH values, hardness and dissolved solids. It is not considered to be detrimental to humans. The maximum amounts of alkalinity permissable in industrial water uses may vary from 30 ppm for carbonated beverage plants to 250 ppm for some food products manufacturing.

60. Examination of the hardness records for the months of December, 1951 to July, 1955 at the Trenton water works intake, indicates a definite cyclical pattern in the occurrence of total hardness. The average monthly total hardness as observed at Trenton in almost all cases reached a peak value in the late fall, decreasing sharply thereafter to a "valley" during the early spring and summer months. A sharp increase was noted during July and August, culminating again in the fall peak. Plotting the average flow at Trenton versus the average total hardness yielded Figure 8. A curve of statistical "best fit" was then drawn. It is seen that as the flow increased, the average hardness decreased, which is due in part to the increased dilution water available. The increase in hardness at the lower flows may be due to an increase in the relative amount of ground water in the Delaware River. Data available for the Delaware in the vicinity of Martins Creek also evidenced the same pattern as that observed at Trenton.



PART B — STREAM QUALITY U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE	FIGURE 8 HARDNESS — FLOW RELATIONSHIP OF DELAWARE RIVER AT TRENTON, N.J. DECEMBER 1951 — JULY 1955

As a generality, Figure 8 could be used as representative of the variation of hardness with flow in the Delaware River.

61. The hardness and alkalinity content of the Delaware River in the vicinity of Milford, Pennsylvania (#3) have remained fairly constant regardless of the flow pattern. Data for the past seven years indicate that the hardness has varied from 15 ppm to a maximum of 30 ppm, with an average of 21 ppm and the alkalinity from 4 ppm to a maximum of 20 ppm. Typical of the hardness content of tributary streams is an average of 12 ppm (1955-1956) for the Neversink River above the Neversink Reservoir. A statistical analysis made between the hardness of the Delaware River below and above Port Jervis indicates that in the summer months there is in general no difference in the hardness of the waters.

62. Conclusions The total hardness and alkalinity of the waters of the Delaware River from its headwaters to Trenton, N. J., from a domestic water supply viewpoint, are not excessive; however, at times the hardness has reached values of 110 to 115 ppm, which has necessitated removal by treatment. As the flow of the Delaware has increased the total hardness content has decreased according to Figure 8.

63. Iron The presence of excess total iron concentrations in a domestic water supply stains laundry and porcelain fixtures and in concentrations higher than 0.5 to 1.0 ppm impart a definite taste to the water.. As a general guideline, the U. S. Public Health Service Drinking Water Standards recommend a suggested limit of 0.3 ppm for the total of the iron and manganese concentrations in the water. From an industrial water use viewpoint, maximum permissable values of iron concentrations vary considerably, depending upon the type of industry, with a minimum value of 0.1 ppm in the manufacture of some pulps and papers.

64. Daily grab samples taken at 9:00 AM at the Trenton water works intake were available for correlational analysis with flow. For seven year record (1948-1955) there does not appear to be any definite year round correlation between the flow at Trenton and the total iron concentration. At the

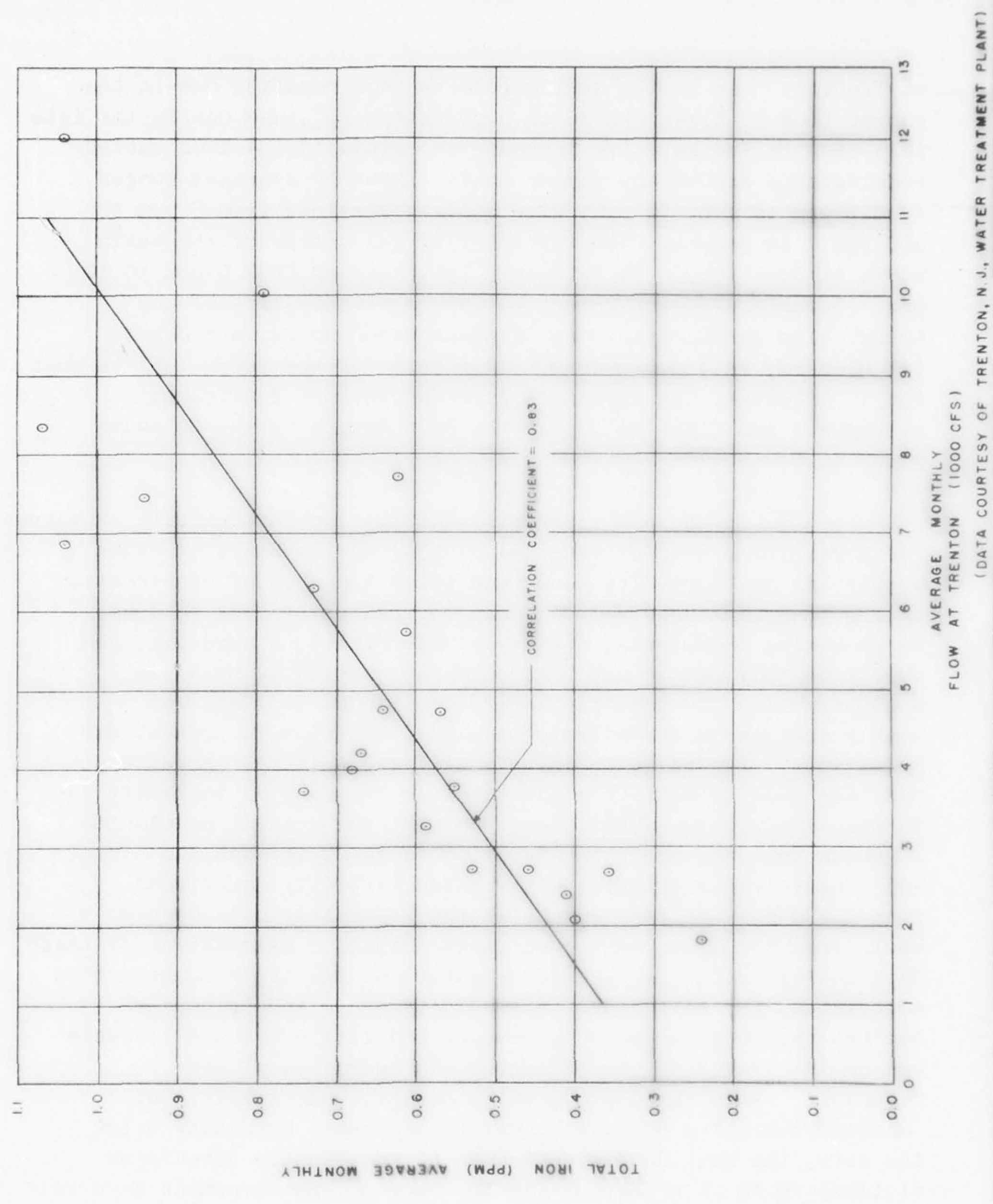
higher flows, the iron content varied between approximately 0.4 ppm and 1.1 ppm, with no visible increase or decrease in this variation as the flow increased. However, during the summer months, a definite pattern exists between the flow and the total iron content. Figure 9 is a plot of the average total iron concentrations for the months of July, August, and September from 1948 through 1955, against the average flow for the month. It is seen that as the flow increases, an increase of about 0.09 ppm of iron per 1,000 cfs occurs. These increasing iron concentrations are believed to be due to the re-suspension of precipitated ferric iron. The correlation coefficient obtained from the statistical analysis of the values indicates that the probability is less than one in one thousand that the relationship occurs by chance alone.

65. Conclusion In general, it can be expected that during the low flow summer months, an increase in the flow tends to increase the total average iron content of the Delaware River at Trenton. The upper waters of the Delaware River exhibited no significant change in the iron content during 1950-1957, when values varied from a minimum of 0.05 ppm to a maximum of 0.70 ppm, with no correlation with flow being evident.

66. Turbidity The presence of turbidity in water interferes with the clarity of the water, and diminishes the penetration of light. It is caused by a number of factors, including organisms, clays and silts, domestic sewage, and industrial wastes. The term should not be confused with the suspended solids content of the water, and may not necessarily bear any relationship. Rather, it is an indication of only one effect of the suspended solids content upon the quality of the water. The U. S. Public Health Service Drinking Water Standards recommend a maximum of 10 ppm for filtered waters. Maximum values of turbidity for industrial water usage may vary from 1 ppm to 100 ppm, depending upon the process.

67. Examination of daily 4-hour grab samples measured for turbidity at Trenton for 1948-1955 did not show any variation with flow. This is due in part to the typical turbidity pattern throughout any given year. Generally three distinct peaks occurred

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

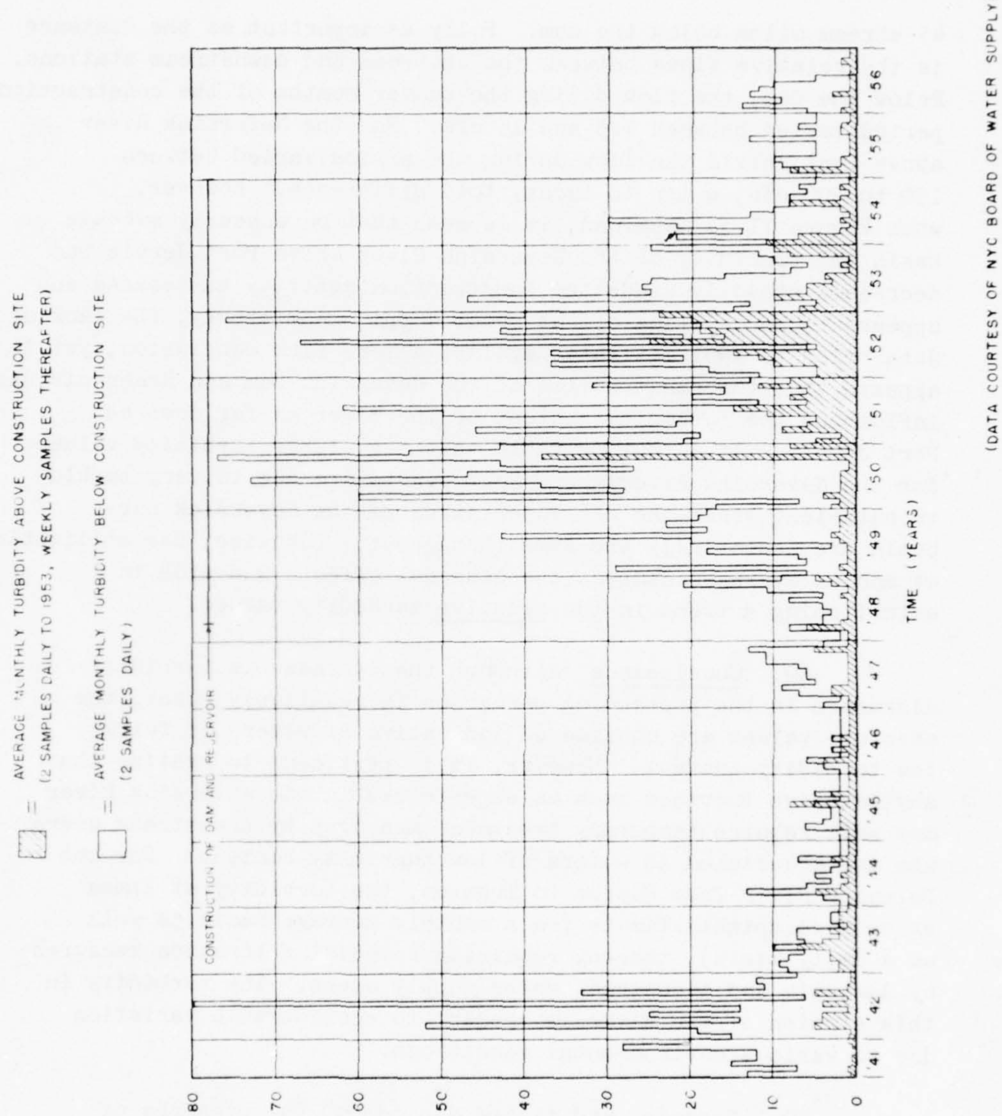
FIGURE 9

IRON-FLOW RELATIONSHIP OF DELAWARE RIVER AT TRENTON, N.J. JULY - SEPTEMBER (1948 - 1955)

at Trenton: one in the spring (due to snow runoff), one in the summer (due to flash storms of high intensity), and one in the late fall (due to the relative increase in rainfall). Values varied considerably across any day or month. Monthly averages ranged from 5 ppm to over 50 ppm, with daily variations from 0 ppm to 500 ppm. In general, the turbidity of the waters of the basin north of Port Jervis is extremely low, varying from 2 ppm to 10 ppm. Occasional peaks occur, but are not indicative of any trend. The turbidity of the Delaware River below Port Jervis (at Milford, Pa.) has averaged only 6ppm for the years 1951 through 1957. Likewise, the Neversink River above Port Jervis has averaged 7 ppm (1951-1957) and the East Branch of the Delaware River at Downsville has averaged 7 ppm (1949-1956).

68. Effect of reservoir construction on turbidity Analyses for turbidity have been made twice daily by the Board of Water Supply for New York City above and below the area of construction of the Neversink Reservoir. These records exist back to 1941. In examining these data, the daily determinations were averaged over a monthly period and Figure 10 was plotted. The daily analyses below the dam site were discontinued in 1953, but weekly analyses are available to extend the plot to present day conditions. Figure 10 is largely self-explanatory. No attempt has been made to ascribe a quantitative increase in turbidity due to the construction activities. Rather, the general conclusion is drawn that the major construction of the Neversink Dam and reservoir has materially increased turbidity downstream from the dam. Analyses were also run separately on a weekly basis from the above mentioned daily samples. Examination of these data indicates that since the cessation of the major construction activities, the difference in turbidity above and below the dam has become progressively smaller and little or no difference can be attributed to the effect of the operation of the reservoir. With the basic premise established, namely that construction of a dam and reservoir increases turbidity below the site, the next determination to be made is the downstream distance which is affected. In the case of the Neversink Reservoir and dam, the closest downstream station after the one immediately below the site is above the City of Port Jervis, a distance of some

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART 3 – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 10
AVERAGE MONTHLY TURBIDITY
NEVERSINK RIVER (1941 – 1956)

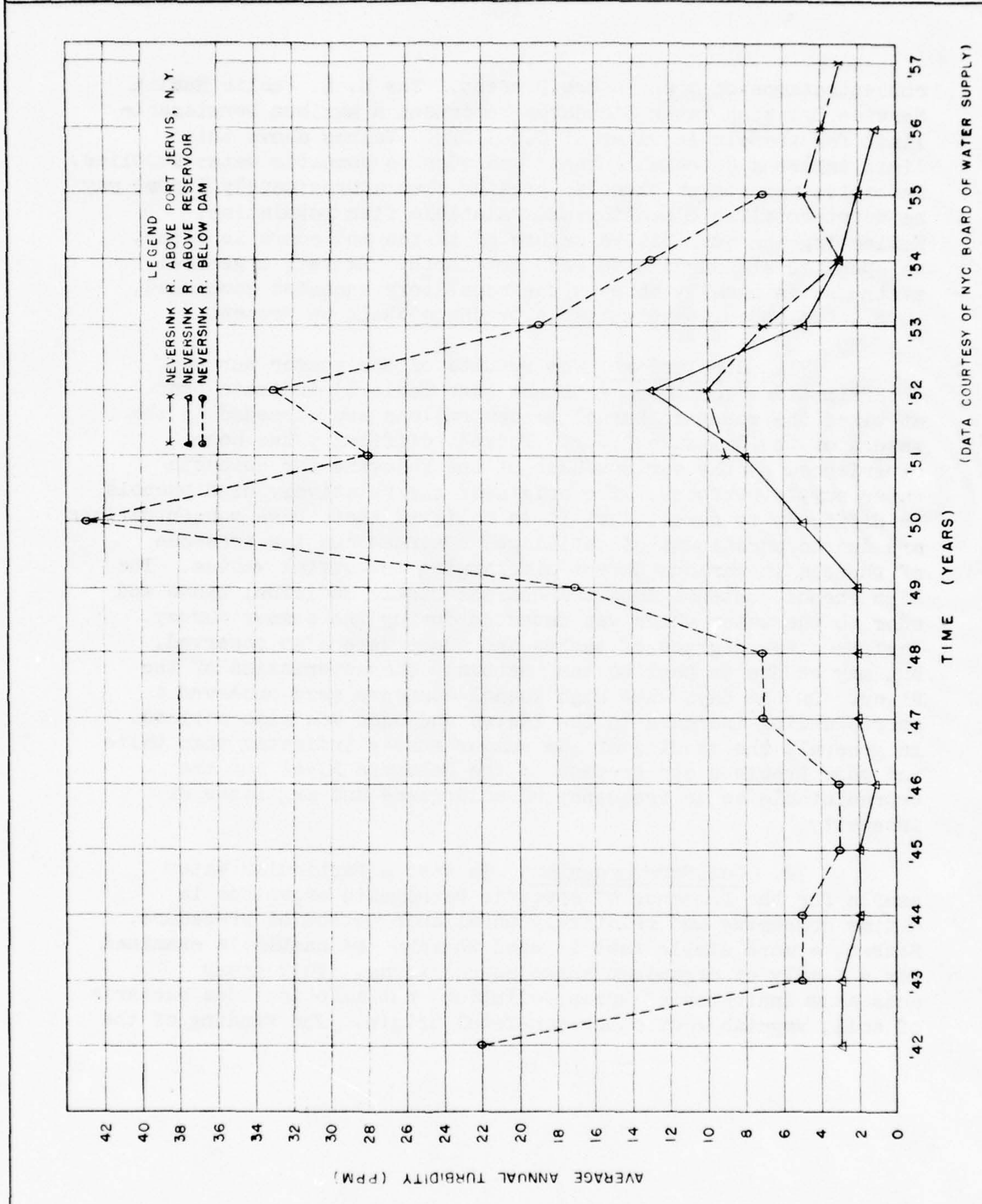
REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF

45 stream miles below the dam. Fully as important as the distance is the relative flows between the upstream and downstream stations. Below the dam, the flow during the summer months of the construction period varied between 7.5 and 15 cfs. For the Neversink River above Port Jervis the flow during the period varied between 150 to 300 cfs, a ten to twenty fold difference. However, when Figure 11 is examined, it is seen that on a yearly average basis the turbidity of the Neversink River above Port Jervis has decreased steadily since the construction activity has ceased and appears to be leveling off at about 4 ppm. Admittedly, the lack of data prior to 1951 mitigates against a more firm conclusion, yet it appears that the construction of the Neversink Dam and Reservoir has influenced the turbidity content of the River as far down as Port Jervis. It is not probable that the higher turbidity values for the Neversink River above Port Jervis are due to very turbid tributaries, since the characteristics of the Neversink sub-basin are essentially the same throughout. Likewise, the utilization of annual averages dampens the seasonal effects and aids in establishing a trend in the relative turbidity values.

69. Conclusions Although the increase in turbidity discussed in the preceeding paragraph is relatively great, the absolute values are considered indicative of waters of fairly low turbidity content. However, it is pertinent to realize that any relative increase such as experienced in the Neversink River may well require temporary treatment measures by downstream users who are accustomed to waters of low turbidity content. For the Delaware River from Easton to Trenton, the turbidity at times exceeds acceptable limits (on a monthly average basis as well as a daily basis), thereby requiring remedial filtration measures by domestic and industrial water supply users. The turbidity in this stretch of the River is subject to considerable variation due to various environmental conditions.

70. Phenols, and tastes and odors The presence of phenols in water is due principally to wastes from such specialized industries as wood distillation industries, oil refineries, and chemical plants. Phenols, in general remain detectable for long distances. A medicinal taste is imparted to the water when excessive

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 11

AVERAGE ANNUAL TURBIDITY NEVERSINK RIVER

concentrations of phenols are present. The U. S. Public Health Service Drinking Water Standards recommend a maximum permissable limit for phenols in water of 0.001 ppm. Values above this limit impart a detectable taste and odor to domestic water supplies. Excessive amounts of phenols (greater than approximately 5 ppm) may be detrimental to a healthy and palatable fish population. Reflecting the qualitative nature of tastes and odors in water, no specific standards have been set forth. Rather, a general statement is usually made by the regulatory agencies concerned, e. g., "no objectionable tastes or odors shall be present."

71. Conclusions The results of the summer survey determinations for phenol content (see Table 6) indicate that at times the accepted phenol concentrations are exceeded in the waters of the Delaware River. Indeed, difficulty has been experienced by the various user of the Delaware for domestic water supply purposes. The origin of the relatively high phenols is difficult to detect, but it is believed that these concentrations are due to occasional oil spillages upstream and the presence of phenols in various direct-discharging industrial wastes. The high phenol contents impart a characteristic medicinal taste and odor to the water which was detected during the summer survey. Various other degrees of tastes and odors were also observed, but may be due in part to the "natural" characteristics of the River. On the days when high phenol contents were observed a corresponding increase in the tastes and odor was also noticed. In general, the results of the summer survey indicated that taste and odor problems are present in the Delaware River but are unpredictable as to frequency of occurrence and magnitude of intensity.

72. Coliform organisms To test a particular water sample for the presence of specific pathogenic organisms is a time consuming and relatively unreliable method of procedure. Rather, a more simple test is used whereby the sample is examined for a family of organisms known as coliforms. This group acts as an indicator of human pollution, but also includes bacteria of soil, vegetable or other non-fecal origin. The finding of the

presence of coliform organisms in a water sample has been accepted as being indicative of sewage pollution. The standard method of expressing coliform concentrations is the most probably numberof organisms per 100 ml of sample. This method of expression is a statistical one and should be viewed as such. Obviously, in sampling a large body of water (or even a distribution pipeline) any one sample analyzed at any one particular time may not necessarily have the same concentration as that taken an instant later. Likewise, the range of magnitude may increase many fold from day to-day, or season to season.

73. The U. S. Public Health Service has recommended placing the results of the coliform determination into four groups as follows:

(a) Group I. Water Requiring No Treatment This group is limited to underground waters not subject to any possibility of contamination, and meeting in all respects, the requirements of the Public Health Service Drinking Water Standards, as shown by satisfactory, regular, and frequent sanitary inspections and laboratory tests.

(b) Group II. Waters Requiring Simple Chlorination, or Its Equivalent This group includes both underground and surface waters, subject to a low degree of contamination, and meeting the requirements of the Public Health Service Drinking Water Standards in all respects, except as to coliform bacterial content, which should average not more than 50 per 100 ml in any one month and exceeding this number in not more than 20% of the samples examined in any one month.

(c) Group III. Waters Requiring Complete Rapid-Sand Filtration Treatment or Its Equivalent, together with Continuous Postchlorination This group includes all waters requiring filtration treatment for turbidity and color removal; waters of high or variable chlorine demand; and waters polluted by sewage to such an extent as to be inadmissable to Groups I and II, but containing numbers of coliform bacteria averaging not more than 5,000 per 100 ml in any one month and exceeding this number in not more than 20% of the samples examined in any one month.

(d) Group IV. Waters Requiring Auxiliary Treatment in Addition to Complete Filtration Treatment and Postchlorination. This group includes waters meeting the requirements of Group III, with respect to the limiting monthly average coliform numbers, but showing numbers of coliform bacteria exceeding 5,000 per 100 ml in more than 20% of the samples examined during any one month and not exceeding 20,000 per 100 ml in more than 5% of the samples examined during any one month.

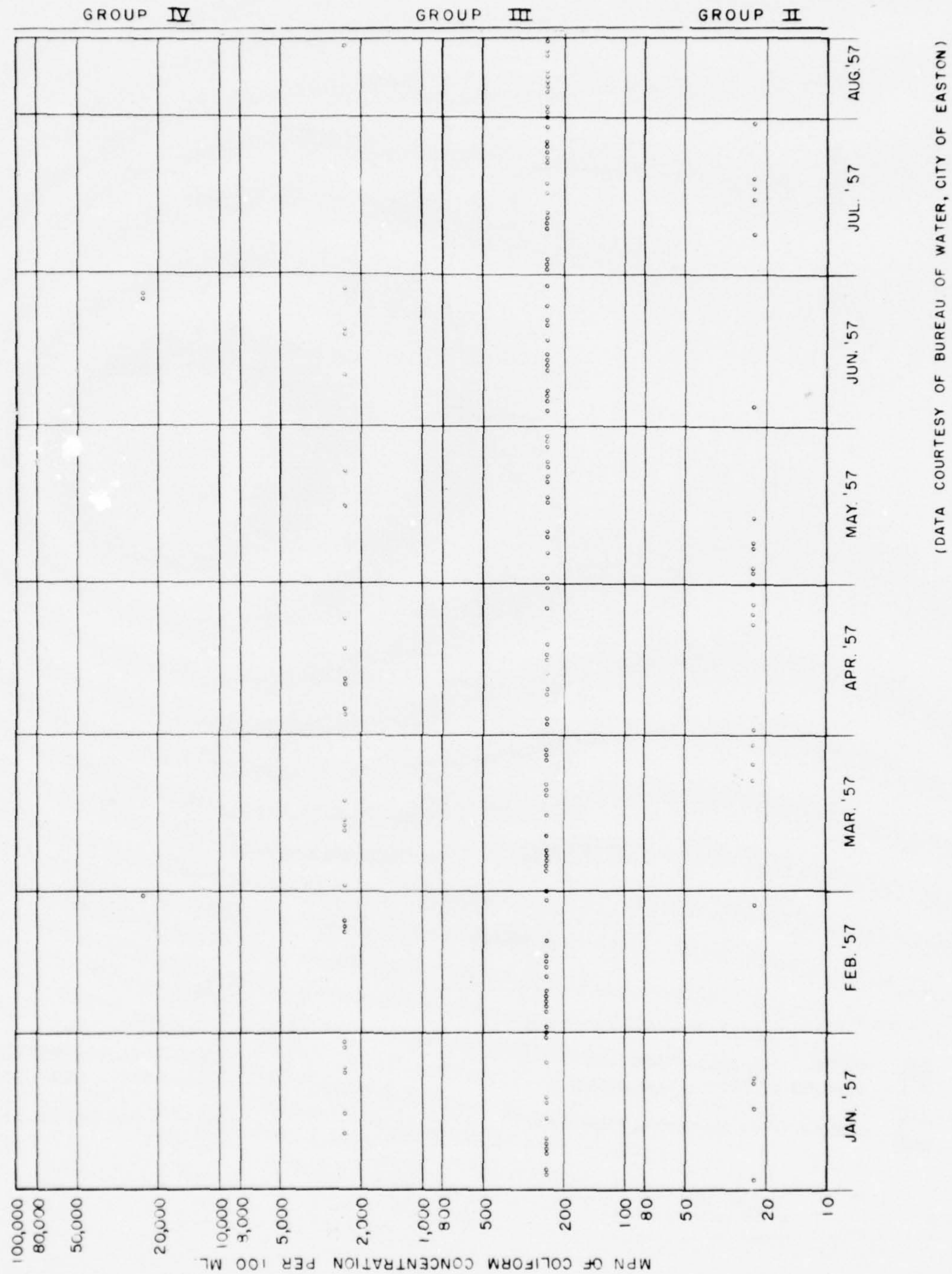
74. Figure 12 is a plot of the coliform concentrations observed at the Easton water works intake. It is seen that in general, the waters of the Delaware River at Easton fall into Group III of the recommendations of the U. S. Public Health Service. The fact that the results obtained fall on a straight line at different levels is a result of the statistical technique used to compute the most probable number.

75. Conclusions In general, it can be said that the coliform concentrations of the Delaware River in the vicinity of Easton is such as to require rapid-sand filtration followed by continuous postchlorination. Also, with a knowledge of the waste discharges from Easton to Trenton, it can be said that the waters in this stretch of the River fall at least into Group III and probably into Group IV.

Future Trends

76. Population The area considered tributary to the Delaware River from Port Jervis to Trenton is outlined in Figure 13. Table 11 presents the basic data on the present and projected future population of this area. As indicated by Figure 13 and Table 11, only those portions of the counties within the basin proper have been considered. The communities tributary to the Delaware within these county sections have been determined from Attachment 1, and the populations thereof from the U. S. Bureau of Census data. When the entire county is within the area, the county populations given by the Office of Business

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 12
COLIFORM CONCENTRATIONS
DELAWARE RIVER AT EASTON, PA.

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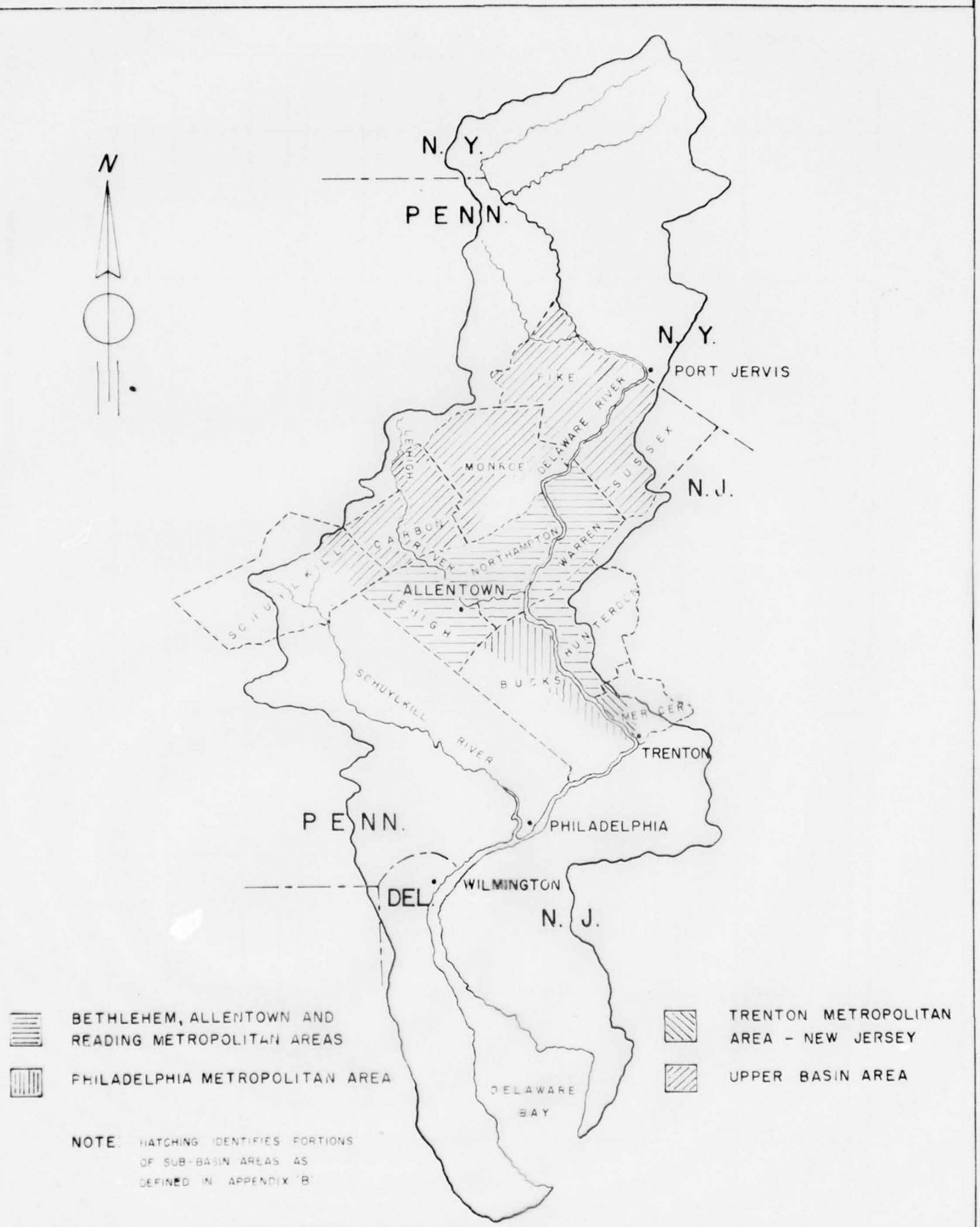


PART B - STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

FIGURE 13
POPULATION TRIBUTARY TO DELAWARE RIVER FROM PORT JERVIS TO TRENTON

TABLE 11

POPULATION OF TRIBUTARY AREAS
(Thousands)

SUB REGION AND COUNTY*	1930	1940	1950	1956**	ESTIMATED FUTURE POPULATION 1965	1980	2010
Sub-region C. (part)							
1. Lehigh (all)	172.9	177.5	198.2	222.0	471.0	576.0	814
2. Northampton (all)	169.3	169.0	185.2	196.0			
4. Warren (all)	49.3	50.2	54.4	58.0	65.2	80.0	155
5. Hunterdon(part)	15.6	16.2	17.8	19.1	21.5	26.4	51
Sub-region G. (part)							
4. Sussex (part)	14.2	15.4	18.1	20.9	24.6	33.5	36
6. Pike (all)	7.5	7.4	8.4	10.0	11.8	16.0	17
7. Monroe (all)	28.3	29.8	33.8	37.0	43.6	50.2	64
8. Carbon (all)	63.4	61.7	57.6	56.0	55.8	55.8	60
Port Jervis, N.Y.	10.2	9.8	9.4	9.8	11.0	13.0	16
9. Schuylkill (part)	5.0	5.5	6.2	6.2	7.0	9.5	10
Sub-region E. (part)							
1. Bucks (part)	27.5	28.6	33.8	36.4	42.3	51.1	97
Sub-region D. (part)							
1. Mercer (part)	6.7	6.9	8.3	9.7	11.6	15.5	25
	569.9	578.0	631.2	681.1	765.4	927.0	1345

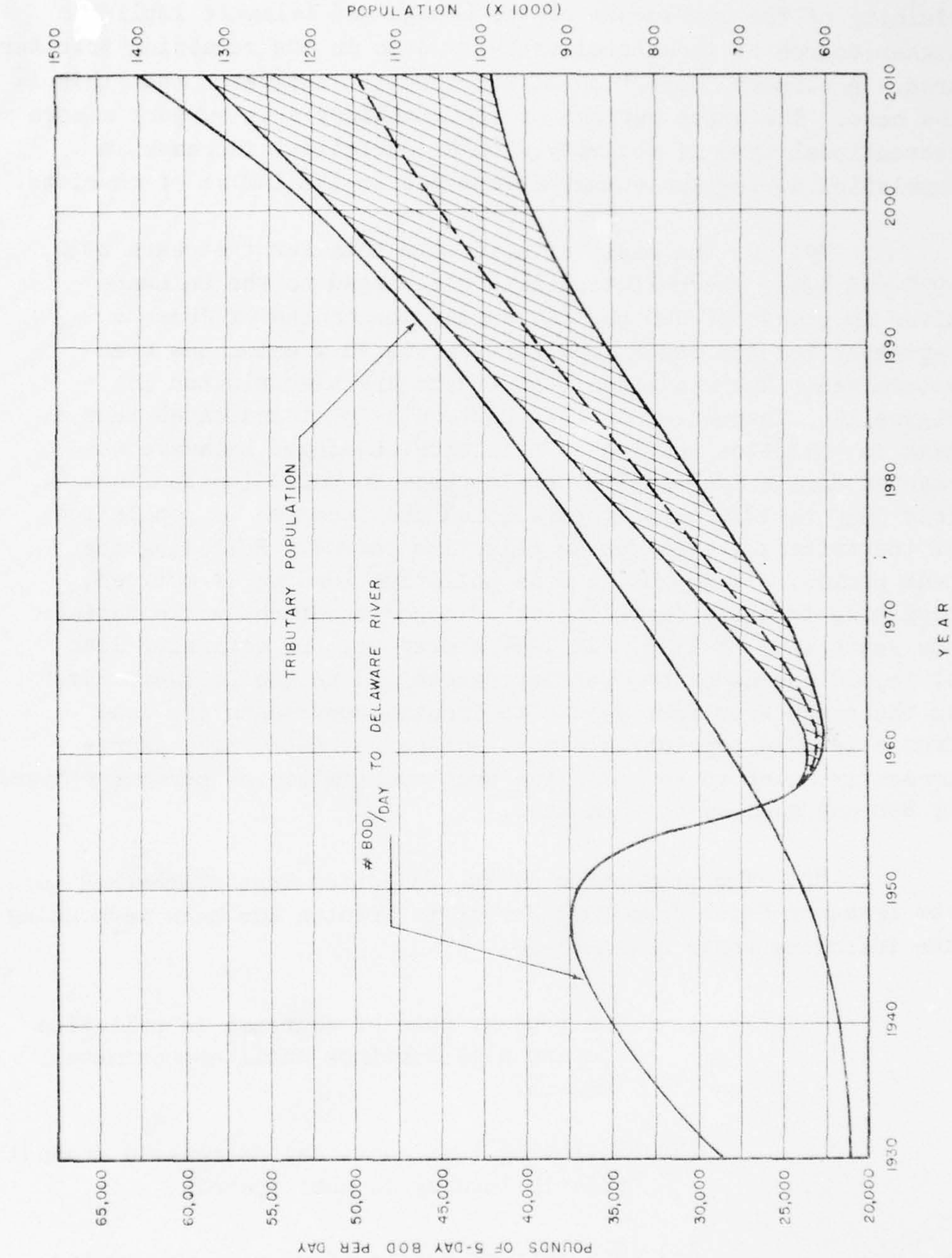
*Refer to Figure 1, Part A
**Estimated

Economics in Appendix B have been used. The projections made for the individual counties and portions of counties have been made using the per cent increases developed by the OBE for the Sub-region in which the county is located. These increases were then applied to the county areas to determine the 1965 to 2010 projected populations. The populations for the tributary area are plotted in Figure 14.

77. The increase in population from 1940 to 1950 is due in large part to the growth of Lehigh and Northampton counties, which formed approximately 70% of the 53,000 population increase in this decade, while constituting 60% of the total tributary population in 1940. However, the per cent increase of Lehigh and Northampton counties was among the lowest of the entire tributary area. All of counties in Sub-region G save Carbon county and the city of Port Jervis (which experienced decreases in population) and those portions of Bucks and Mercer counties within the basin area, experienced per cent increases in populations during 1940 - 1950 greater than Lehigh and Northampton counties. It is anticipated, however, that both these counties will undergo a rise in population commensurate with the surrounding area. In 1956 it is estimated that Sub-region C as indicated in Table 11 formed 73% of the total tributary population. It is estimated that in 1965 and 1980, this portion will constitute approximately the same percentage of the total tributary population. It is seen then that the greater portion of the population shown in Figure 14 is concentrated in the Lehigh River sub-basin and in the area surrounding the confluence of the Lehigh River with the Delaware.

78. Pollution loading Of the total population of 681,000 in the tributary area in 1956, 341,600 or approximately 50% were served by sewer systems. The remaining population utilized individual means of waste disposal. Of the 341,600 people sewered, 95.6% or 326,000 were served by secondary sewage treatment facilities. In the entire area, there is only one primary plant serving approximately 1,000 people and four sources of untreated wastes from sewered communities. The concentration of population in the Lehigh River basin and in the

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B — STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

FIGURE 14
TRIBUTARY POPULATION AND POLLUTION LOAD
DELAWARE RIVER — PORT JERVIS, N. Y. TO TRENTON, N. J.

vicinity of the confluence of the Lehigh and Delaware implies a higher degree of industrial activity than in the remaining tributary area. A cursory inspection of Attachment 1 indicates that this is the case. The upper regions of the tributary area support a more recreational type of activity with a concomitant increase in population during the summer months due to the influx of tourists.

79. On the basis of available data for the years 1930, 1950 and 1956, the pollution load discharged to the Delaware River in pounds of BOD per day during the months of June to September for the reach from Port Jervis to Trenton has been determined. The results of these data are also plotted in Figure 14. Inspection of this particular plot indicates that a peak in pollution loading in this stretch of the Delaware was reached during 1949-1951. The increase in pollution loading from 1930 to 1950 closely paralleled the increase in population of the tributary area during this time period. Following the peak period, a sharp decline in pollution loading is noticed, resulting from the installation of major treatment works during the years 1953 to 1956. In 1956 therefore, the estimated load of 24,000 pounds of BOD per day discharged to the Delaware River in the reach from Port Jervis to Trenton represents the load from a sewered population almost entirely treated to a degree presently accepted as being the best combination of percent removal of BOD and economy of treatment.

80. The projection of the pollution load discharged to the Delaware River from Port Jervis to Trenton has been made using the following basic assumptions:

(a) The present rate of decrease in pollution loading will continue until approximately 1962-65.

(b) Following this continual decrease a gradual rise in loading is anticipated.

(c) The rate of this gradual rise in loading will soon approach the rate of increase in population.

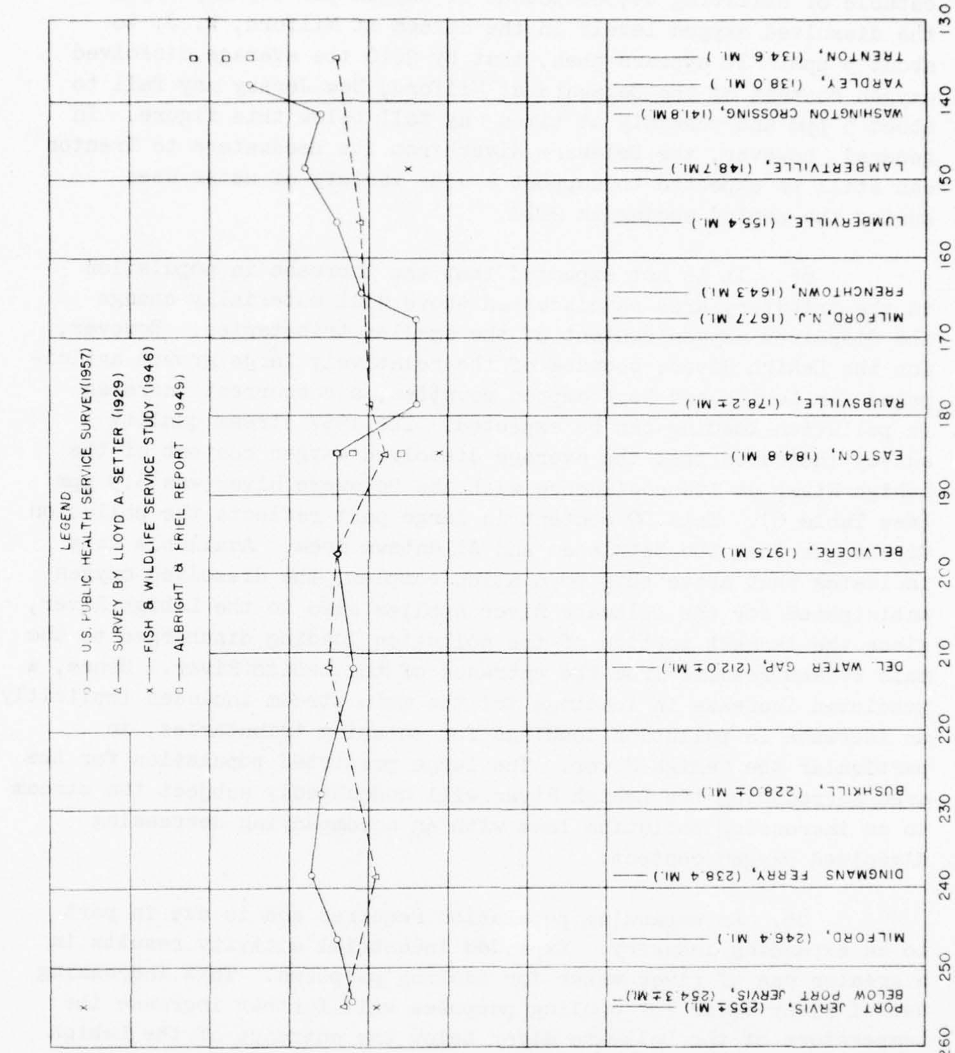
81. More than 95% of the sewered population is served by secondary treatment facilities. The overall amount of pollution removed by these plants is at present slightly higher than the recognized efficiency obtainable from a secondary plant of approximately 80 - 90%. Consequently, as these secondary plants utilize their expected design capacities (in terms of amount of sewage to be treated) there will be a slight decrease in pollution loading. As the population continues to increase at the rather rapid rate shown in Figure 14, the present treatment plants will reach and surpass their design capacity. Also, expanding population results in an increasing population density pattern requiring communities to install common sewerage systems. With the increase in loading on present treatment plants and the increase in sewered population (tending to concentrate pollution loadings at a specific point), an increase in the overall load to the Delaware River can be expected. It is evident therefore, that unless sewage treatment technology increases to the point where pollution removal is increased beyond present day methods, the mere increase in the population of this area which is now 50% sewered, of which 95% is served by secondary treatment plants, will result in an ever-increasing pollution load to the Delaware River. The projected pollution load indicated in Figure 14 is based on the above discussion. Obviously, only the general trend is of value; specific loading figures are subject to considerable variation. Because of this and the need to arrive at an order of magnitude regarding the amount of load to be expected, a range of possible values has been used in the projections. It is anticipated that by 1965 and 1980, the total amount of pollution expressed in pounds BOD/day discharged to the Delaware River from Port Jervis to Trenton will lie somewhere within the boundaries of the band indicated in Figure 14.

82. The population of the tributary area in 2010 is expected to be approximately 1,400,000, 70% of which will be concentrated in Lehigh and Northampton counties. Continuing the assumptions expressed previously regarding the increase in pollutional load, it is expected that by 2010, the total discharge to the Delaware River in the reach from Port Jervis to Trenton is expected to be about 50,000 pounds of BOD per day. Again, only the general trend is of value and even a wider variation in the projection is impossible. This is indicated in Figure 14.

83. Stream quality The discussion of future water quality conditions in this and subsequent paragraphs assumes no changes in the flow regime of the streams of the Basin. The effect of any proposed impoundments on future stream quality is discussed in Part C of this Appendix. Figure 15 presents the results of various sampling programs performed on the Delaware River. The two major surveys performed in 1929 and 1957 indicate more specifically the DO profile during these years. The grab samples plotted in Figure 15 serve to fill the gap between the 1929 study and the 1957 study. It is seen that at no time during these studies did the dissolved oxygen content fall below 7 ppm. On the basis of the 1957 stream Survey, it was concluded (see paragraph 56) that if a pollution load were introduced into the Delaware River above Raubsville, Pennsylvania and was of such a magnitude as to utilize 44,500 lbs. of oxygen in its stabilization, the dissolved oxygen content of the River at Milford, New Jersey may fall to as low as 5 ppm. Examining Figure 14, it is seen that the worst condition anticipated in 1980 is a pollution load of approximately 37,000 lbs. BOD/day. This represents the pollution load discharged to the Delaware River in the entire reach from Port Jervis to Trenton, New Jersey. It appears therefore, that the Delaware River at its present low point of dissolved oxygen (Raubsville-Milford area) has sufficient capacity to absorb the anticipated pollution load in 1980 without lowering the average dissolved oxygen content below 5 ppm.

84. The estimates of stream quality conditions in 2010 are subject to wide variations, but on the basis of past trends and the projected pollutional load to the Delaware River, certain general statements are possible. The pollutional load of 50,000 pounds of BOD per day expected in 2010 includes discharges to the Delaware in the entire stretch from Port Jervis to Trenton. A large undetermined part of this load, however, will be concentrated at the entrance of the Lehigh River. It is highly probable that the load above Raubsville will approach 45,000 lbs of BOD per day. As mentioned in the preceding paragraph, it was concluded that the introduction of a waste load above Raubsville, Pennsylvania

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B — STREAM QUALITY

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 15
DISSOLVED OXYGEN PROFILES

capable of utilizing 44,500 pounds of oxygen per day may depress the dissolved oxygen levels in the stream at Milford, N. J. to about 5 ppm. It appears then, that by 2010 the average dissolved oxygen content of the Delaware at Milford, New Jersey may fall to about 5 ppm and possibly at times may fall below this figure. In general, however, the Delaware River from its headwaters to Trenton can still be expected to support a wide variety of water uses during the period ending in 2010.

85. It is not expected that the increase in population in the tributary area as discussed above will materially change the dissolved oxygen content of the smaller tributaries. However, for the Lehigh River, because of the relatively large growth anticipated for Lehigh and Northampton counties, a concurrent increase in pollution loading can be expected. The 1957 stream quality survey indicated that the average dissolved oxygen content of the Lehigh River at its confluence with the Delaware River was 5.9 ppm (see Table 6). This DO content in large part reflects the pollution discharges from the Bethlehem and Allentown area. Available data indicates that above this population complex, the dissolved oxygen anticipated for the Delaware River applies also to the Lehigh River, since the largest portion of the pollution loading discharged to the main stream results from the entrance of the Lehigh River. Hence, a predicted increase in loadings for the main stream includes implicitly an increase in pollution loadings for entering tributaries, in particular the Lehigh River. The large predicted population for the area surrounding the Lehigh River will undoubtedly subject the stream to an increasing pollution load with an accompanying decreasing dissolved oxygen content.

86. An expanding population requires and is due in part to an expanding industry. Expanded industrial activity results in a greater use of river water for cooling purposes. This increasing use of river water for cooling purposes will further increase the temperature of the Delaware River below the entrance of the Lehigh River. Also, for the Lehigh itself, the discharge of high temperature process water is at present resulting in a definite increase in stream

temperature below the Bethlehem-Allentown area. Table 6 indicated the relatively high average temperature of the Lehigh River at the entrance with the Delaware. Available data indicates that above the Bethlehem-Allentown area, normal fluctuations in water temperatures occur with a high of approximately 22°C. during the summer months. Below the metropolitan complex, summer temperatures reach a high of approximately 26°C. It is expected then that the increase in temperature from above the Bethlehem-Allentown area to below this area will at least be maintained and may possibly increase to a slight degree.

87. With respect to the remaining stream quality characteristics, it is estimated that the increasing pollution load will result in increasing concentrations of all of these parameters in varying degrees. For example, it is obvious that increasing pollution loads will produce an increase in the bacterial content of a stream, whereas this increase in loading will affect the hardness content of the stream to a considerably lesser degree. The latter effect is due to the fact that a large percentage of hardness in a stream is due to the geological factors of the basin. Increases in hardness can occur as a result of specialized industries. For purposes of this report, however, no attempt has been made to project any increases in the chemical constituents of stream quality.

SECTION IV

STREAM QUALITY OF DELAWARE RIVER BASIN FROM TRENTON, NEW JERSEY TO DELAWARE BAY

Previous Work

88. Numerous water quality studies have been made of the Delaware River estuary. One of the earliest studies of the main stream was conducted in the years 1939 to 1940 by the U. S. Corps of Engineers[4] to assess the extent of the oil problem in the navigable waters of the Delaware River. As an adjunct to the study of oil pollution, weekly samples consisting of determinations for dissolved oxygen, BOD, coliform-organisms and bacterial-plate counts were taken at a total of 12 sampling stations ranging from Trenton, New Jersey to Reedy Island, Delaware. Additional samples were also obtained from the significant tributaries near their entrances with the main stream. During 1940, the weekly sampling routine was limited to two stations on the main stream (Trenton and Fort Mifflin) and to Frankford Creek and the Schuylkill River.

89. A study of pollution loadings and tidal movements with reference to salinity characteristics was conducted during 1940.[5] Pollution loadings were estimated using tributary populations, standard industrial wastes loading characteristics and other pertinent facts. Displacement times in the estuary were computed under a variety of fresh water in-flow conditions and various patterns of salinity encroachment were computed.

90. In 1943, the New Jersey State Health Department conducted a limited water quality survey during the months of June and August.[6] Stations similar to those reported in the Corps of Engineers study were occupied during this survey and similar quality determinations were made.

91. In 1946 the Department of Interior Fish and Wildlife Service conducted a water quality survey of the estuary to determine the effects of pollution on shad migration upstream 3/. Although a total of 15 stations were occupied during the survey considerably more emphasis was placed on the station located at Pennsville, New Jersey.

92. Since 1952 the Delaware Bay Institute and New Jersey Oyster Research Laboratory have been obtaining river samples along a run consisting of the range from Ship John Light to the Delaware River above the entrance of the Schuylkill River. These runs (initially known as "Delzoop", and presently known as "JD" runs) consist of analyses made for salinity, temperature and dissolved oxygen at mid-channel and at 20 foot depth intervals.

93. The City of Philadelphia Water Department on occasion samples the estuary at varying locations extending from approximately Allegheny Avenue to Reigelsville, New Jersey. These studies are conducted principally to maintain a continuing check on the quality of the Delaware river water with special reference to phenol bearing wastes. Also routine weekly sampling started in 1949, is conducted by the Torresdale water plant to determine the quality of the estuary at that particular point.

94. In 1956 a study 7/ was run by the Delaware Water Pollution Control Commission of the water quality of the Delaware estuary from Appoquinimink River to the Delaware-Pennsylvania state line at Marcus Hook. The samples were analyzed comprehensively including determinations for DO, BOD, temperature, chlorides, hardness, alkalinity, color, etc. Following this study the Delaware Water Pollution Commission has continued to make sampling runs and has extended the runs upstream to Fieldsboro, New Jersey.

95. Since August 1949, a total of 8 stations ranging from the Burlington Bristol bridge to Marcus Hook, Pa. have been sampled on a monthly basis in a cooperative survey program by the City of Philadelphia and the U. S. Geological Survey. 8/ The river is cross-sectioned into 5 locations consisting of New Jersey side, New Jersey side of channel, Center of channel, Pennsylvania side of channel, and shore. Likewise, samples are taken at these sections at

3 feet below the surface and 3 feet above the river bottom. Analyses consist of DO, BOD, temperature, chlorides and other chemical tests.

96. In addition to the studies mentioned above there are many private industries located along the estuary which routinely sample the river water in order to maintain a close check on quality conditions. The data from the above mentioned studies have been included as far as possible in this report. Special use has been made of data collected on a systematic basis with the earlier studies (prior to 1949) serving to establish general quality trends.

Waste Sources

97. Attachment 1 presents the basic data on sources of pollution discharging to the Delaware Basin waters. Table 12 abstracted from this attachment indicates the total population equivalent load discharged directly to the main stream as well as those loads contributed by tributaries. These tributary loads have been considered as point sources representing the pollutional effect on the Delaware River of discharges upstream. It is seen from Table 12 that the load discharged directly to the river is considerably greater than the load discharged by tributaries. Considerable progress has been made in the elimination of discharges into the tributaries of the estuary, notably the Schuylkill and Cooper Rivers and Darby and Frankford Creeks. However, the elimination of the pollution of tributaries has resulted in localizing the point of discharges of wastes into the main stream proper. With the construction of long interceptor lines along the river front, the question of loadings contributed by storm overflow chambers has become one of paramount importance. At the present time, the state of knowledge of the magnitude of these loads is extremely limited. The exact amount is undetermined and the total pollution load discharged directly to the river as indicated in Table 12 should be viewed with this additional element as a potential short-term pollution load.

TABLE 12

BASIC DATA ON SIGNIFICANT WASTES DISCHARGED DIRECTLY TO THE DELAWARE RIVER ESTUARY FROM TRENTON, N. J. TO DELAWARE BAY. (1958)

River Mile Section* or Tributary		Estimated Pound 5-Day BOD Discharged Per Day
135 - 130		40,950
133.4	Assunpink Creek	1,500
129 - 125		4,810
128.4	Crosswicks Creek	4,660
124 - 120		2,740
119 - 115		3,050
114 - 110		460
111.2	Rancocas Creek	3,270
109 - 105		1,460
105.4	Pennsauken Creek	2,360
104 - 100		182,120
103.0	Cooper River	4,080
99 - 95		112,500
96.8	Newton Creek	3,360
95.4	Big Timber Creek	1,700
94 - 90		95,870
92.0	Schuylkill River	42,740
91.6	Woodbury Creek	1,670
89 - 85		82,710
89.5	Mantua Creek	2,750
85.2	Darby Creek	2,800
84 - 80		24,700
79 - 75		40,180
74 - 70		91,390
69 - 65		1,900
64 - 60		13,800
Smaller tributaries not listed above		470

* All river miles referred to mouth of Delaware Bay = 0.0

Analysis and Interpretation of Data

98. General The method outlined in Attachment 2 - Technical Discussions was performed on data collected in the estuary over the past nine years by various agencies and individuals. These data were outlined in paragraphs 88 - 96. The analysis discussed in detail in Attachment 2 provides information regarding the variations in a particular quality variable at a specific point in the estuary under a variety of assumed conditions. Briefly, the analysis assumes that a particular water quality variable at a point in the estuary varies sinusoidally across three time periods. It is possible from the analysis to determine, for example, the average dissolved oxygen at a particular location for different periods of the tide, time of day, or time of year and various combinations of these influences. The periods used were the time of year, time of day and time of tide. Statistical tests can be performed on the results obtained to check the original assumption.

99. Prior to the initiation of the cooperative stream quality studies by the City of Philadelphia and the U. S. Geological Survey in 1949, the stream quality data were collected at odd intervals at many different locations in the estuary. The stations occupied during this study are indicated in Figure 16 and a description of the stations is contained in Table 13. The data collected by the Delaware Water Pollution Commission at the stations indicated in Figure 16 and Table 13 were combined with the City of Philadelphia - U. S. Geological Survey data. The amount of data at the other stations occupied by the Water Pollution Commission was insufficient for analysis. The Delaware Water Pollution Commission data have formed the major part of the material analyzed in the stations below Marcus Hook.

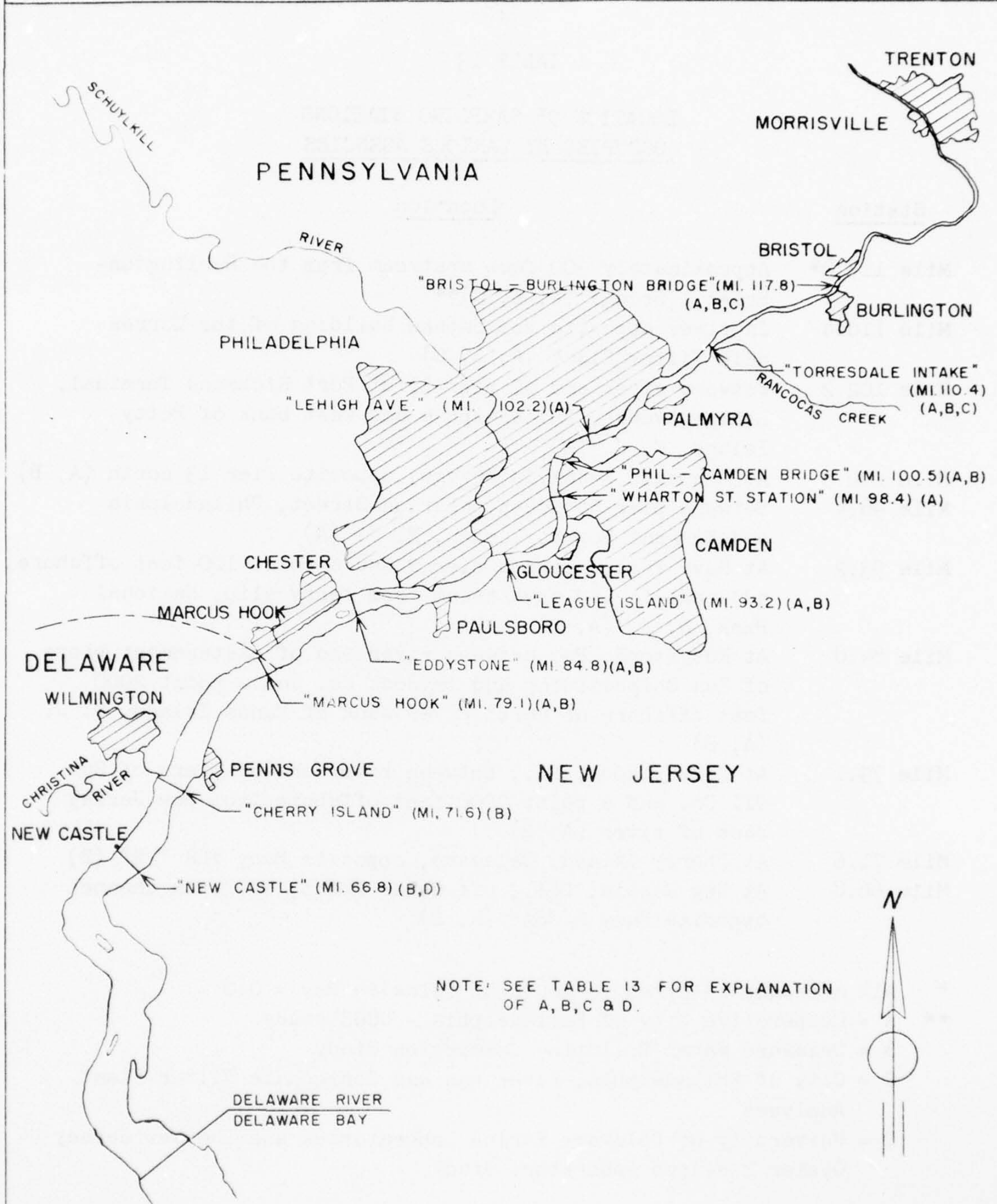
100. The remaining data incorporated into the analysis were obtained from the following agencies:

(a) University of Delaware Marine Laboratories

(b) New Jersey Oyster Research Laboratory

(c) Philadelphia Water Department - River runs and Torresdale Water Treatment Plant analyses.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B - STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 16

LOCATION OF SAMPLING STATIONS

DELAWARE RIVER ESTUARY

TABLE 13

LOCATION OF SAMPLING STATIONS
OCCUPIED BY VARIOUS AGENCIES

Station	Location
Mile 117.8*	Approximately 300 feet upstream from the Burlington-Bristol Bridge (A, B, C)**
Mile 110.4	In river opposite the intake building of the Torresdale Filter Plant (A, B, C)
Mile 102.2	Between river end of pier 11 at Port Richmond Terminal, Lehigh Avenue, Philadelphia and west bank of Petty Island, N. J. (A)
Mile 100.5	At Benjamin Franklin Bridge, opposite Pier 13 north (A, B)
Mile 98.4	Between pier 55 south, Wharton Street, Philadelphia and Kaighns Point, Camden, N. J. (A)
Mile 93.2	At Navy Yard, between pier 2 and a point 100 feet offshore, adjacent to and downstream from ferry slip, National Park, N. J. (A, B)
Mile 84.8	At Eddystone, Pa. between river end of easternmost piers of Sun Shipbuilding and Drydock Co. and a point 2000 feet offshore of north river bank of Munds Island, N. J. (A, B)
Mile 79.1	At Marcus Hook, Pa., between river end of piers of Sun Oil Co. and a point 2000 feet offshore from New Jersey bank of river (A, B)
Mile 71.6	At Cherry Island, Delaware, opposite Buoy FLR "2B" (B)
Mile 66.8	At New Castle, Del., off Cedar Point, N. J. in channel opposite Buoy R "6A" (B, D)

* All mileages referred to mouth of Delaware Bay = 0.0

** A = Cooperative City of Philadelphia - USGS study
B = Delaware Water Pollution Commission Study
C = City of Philadelphia, river run and Torresdale Filter Plant Analyses
D = University of Delaware Marine Laboratories and the New Jersey Oyster Research Laboratory Study

Although some of these data sources occupied additional stations than those shown in Figure 16, the amount of data at these interim stations was insufficient for analysis.

101. For the ten stations indicated in Figure 16, a total of some 9,000 samples upon which some 45,000 analyses were performed was available. These analyses consisted mainly of temperature, chlorides, dissolved oxygen, biochemical oxygen demand and other analyses such as hardness and color. These data represent the quality of the estuary from August 1949 to July 1958, the cut-off date for purposes of this report. The data were coded on punch cards for analysis by a high speed computer. The channel data consisting of samples collected at the two sides of the channel and the center of the channel were combined into one group and designated as "center". This was a reasonable grouping since inspection of the data and prior work have indicated little differences between these points. Also, the width of the channel is relatively small (averaging 400 feet) compared to the distance from the channel to the west and east shores. The remaining data were grouped into west and east shore categories. The above groups were further classified according to top and bottom, where "top" represents those samples collected between the surface and a depth of 5 feet and "bottom" represents those samples collected within 0 - 5 feet of the river bottom. This resulted in a set of six "decks" of punched cards for each of the eight stations above Marcus Hook and two "decks" for the stations below Marcus Hook where samples were taken at the surface of the channel. All "top" decks were then individually analysed for specific stream quality variables. Time and fund limitations prevented a complete analysis of "bottom" decks.

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102. <u>Temperature</u> Table 14 summarizes the results of the analyses performed on the temperature data. The detailed results are presented in Attachment 2. A high degree of correlation and significance was obtained at all stations from the analyses of the temperature data. The initial sinusoidal hypothesis postulated in paragraph 98 has therefore been substantiated. Therefore, the summary of results in Table 14 presents an accurate description of the temperature of the Delaware River estuary. The peak seasonal temperatures indicated in Table 14 occur throughout the estuary during the latter part of July. Attachment 2 presents the details of the times of occurrence. From Table 14, it is seen that at some stations, there are considerable differences in water temperature between the channel and east and west shores. These lateral differences from shore to shore are attributable mainly to two separate causes: (a) the physical configuration of the estuary, i. e. wide shallow areas, pools etc. and (b) high temperature man-made discharges.

103. Figure 17 is a plot of the typical channel temperature variations at two stations, Benjamin Franklin Bridge and Marcus Hook. It is seen that the seasonal variation is considerably greater than both the tidal and daily variation. The tidal variation at Marcus Hook is not plotted because the statistical tests did not prove the significance of the relationship. For a more complete discussion of this, see Attachment 2 - Technical Discussions.

104. Figure 18 is a plot of the profile of channel temperature of the estuary from Burlington-Bristol Bridge to New Castle, Delaware obtained from the values presented in Table 14. This profile indicates that the grand average channel temperature throughout the estuary varies from a low of 11.6° C. at the Navy Yard to a high of 15.2°C at Torresdale. However, the changes in peak seasonal temperatures as indicated by the shaded area become considerably greater as the industrial density increases, reflecting the increased utilization of river water for cooling purposes. The contrast between the reach above Lehigh Avenue and downstream reach is apparent. Also, the effect of the waters of the Schuylkill River can be observed. This effect is more pronounced during the tidal and daily cycles, thereby producing the relatively large range in maximum water temperatures.

TABLE 14

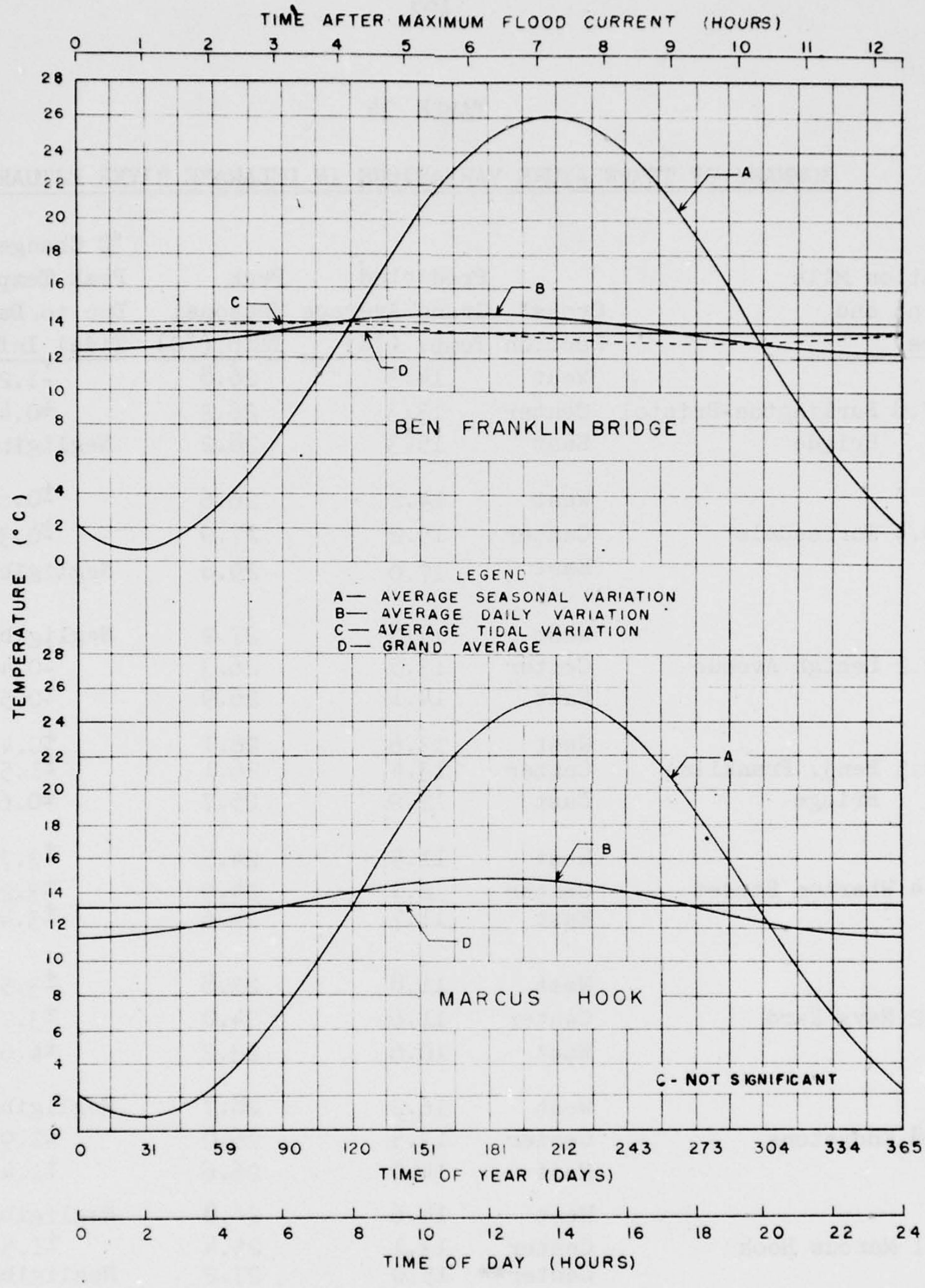
SUMMARY OF TEMPERATURE VARIATIONS IN DELAWARE RIVER ESTUARY

Station Mile Point and Name	Cross* Section	Predicted Grand Average Temp. (°C)	Peak Seasonal Temp.(°C)	°C Change in Peak Temp. Due to Daily and Tidal Influences
	West	14.3	26.8	±1.2
117.8 Burlington-Bristol	Center	13.3	26.2	±0.4
Brigde	East	15.3	28.2	Negligible
	West	14.2	26.6	±0.6
110.4 Torresdale	Center	15.2	27.9	±0.3
	East	17.0	29.8	Negligible
	West	14.8	27.2	Negligible
102.2 Lehigh Avenue	Center	13.5	26.3	±0.4
	East	14.1	26.9	±0.5
	West	13.6	26.1	±0.4
100.5 Benj. Franklin	Center	13.4	26.1	±1.5
Bridge	East	12.9	25.7	±0.6
	West	11.9	24.5	±3.7
98.4 Wharton Street	Center	12.1	24.9	±3.2
	East	11.7	24.6	±3.4
	West	11.8	23.8	±3.5
93.2 Navy Yard	Center	11.6	24.0	±3.7
	East	10.6	23.2	±4.6
	West	16.2	28.7	Negligible
84.8 Eddystone	Center	13.5	26.0	±1.9
	East	14.0	26.6	±1.4
	West	14.6	26.8	Negligible
79.1 Marcus Hook	Center	13.1	25.4	±1.5
	Center**	15.0	27.2	Negligible
	East	14.0	26.5	Negligible
71.6 Cherry Island	Center	15.2	26.5	±1.4
66.8 New Castle	Center	15.0	25.9	±1.4

*Values are for surface only, unless otherwise noted

**Bottom values

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

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FIGURE 17

TYPICAL TEMPERATURE VARIATION

DELAWARE RIVER ESTUARY

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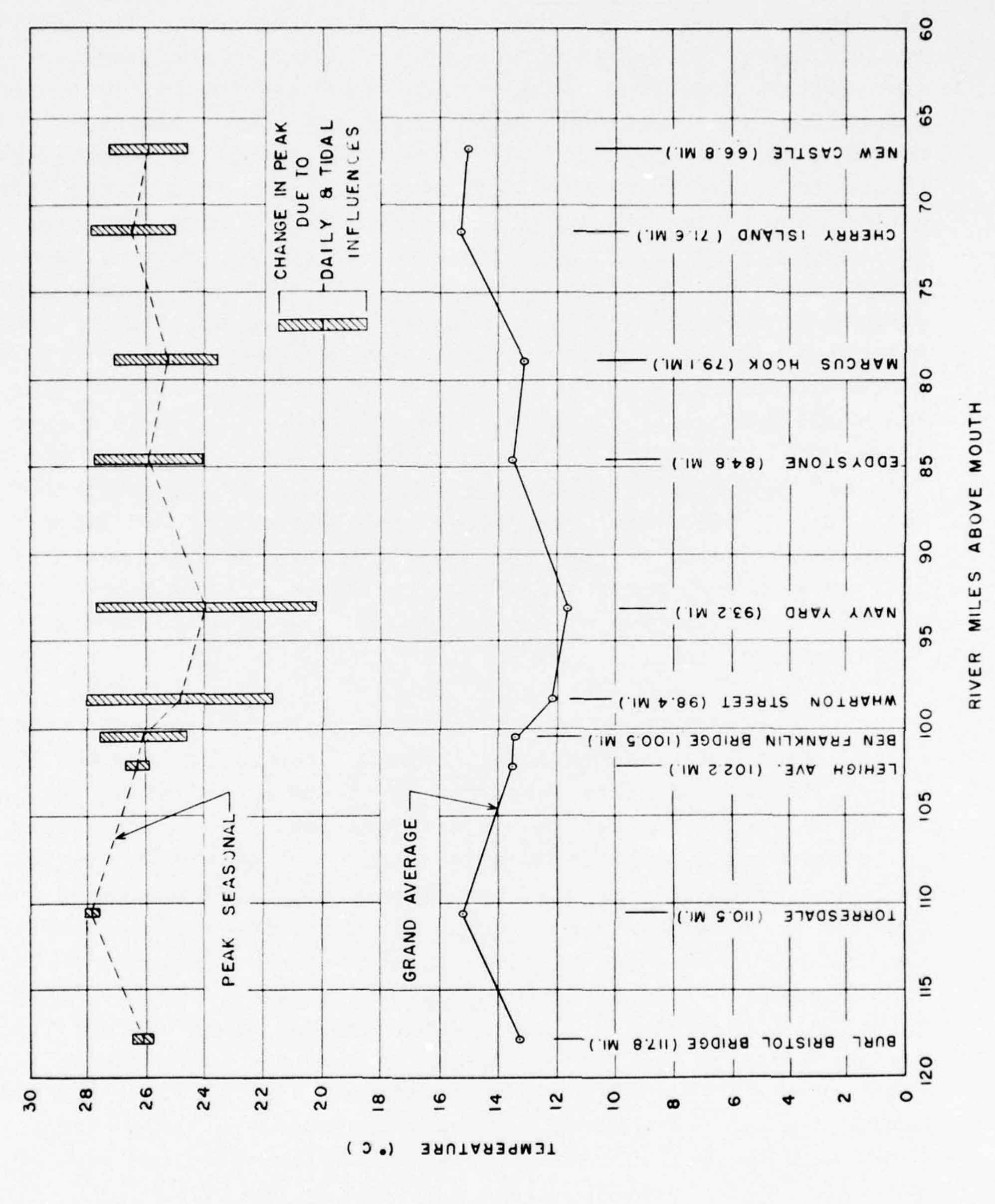

PART B – STREAM QUALITY

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FIGURE 18

TEMPERATURE PROFILE

DELAWARE RIVER ESTUARY

105. Dissolved Oxygen Table 15 summarizes the results of the analyses performed on the dissolved oxygen data. The detailed results are presented in Attachment 2. Although analyses were made both on dissolved oxygen in parts per million and in percent saturation, the dissolved oxygen in ppm was used exclusively. This approach was used in order to separate the effect of temperature. Dissolved oxygen in percent saturation includes this effect thereby, masking the variations in water temperature. A high degree of correlation and significance was obtained at all stations from the analyses of the dissolved oxygen data. As with temperature, the initial sinusoidal hypothesis proposed in paragraph 98, has been validated and the results obtained provide an accurate description of the dissolved oxygen variations in the Delaware River estuary. The minimum seasonal dissolved oxygen listed in Table 15 occurs during the latter part of May below Marcus Hook and the latter part of July and beginning of August above Marcus Hook. The details of each time of occurrence are presented in Attachment 2. Inspection of Table 15 indicates the lateral differences in dissolved oxygen. Like temperature, these differences arise mainly from either the physical configuration of the estuary or man-made discharges or a combination of both.

106. Figure 19 is a plot of the dissolved oxygen variations in the channel at two stations; Benjamin Franklin Bridge and Marcus Hook. Statistical tests performed on the daily variation at Benjamin Franklin Bridge showed that the variation across a day was statistically nonsignificant. During a complete tidal cycle at Benjamin Franklin Bridge, the minimum dissolved oxygen value occurs approximately 3 hours after maximum flood current time. This corresponds to the time of slack flood current. However, for a complete tidal cycle at Marcus Hook, the minimum dissolved oxygen value is approximately 10 hours after maximum flood current time, corresponding to the time of slack ebb current. This may be expected since the pollution from upstream sources first reaches Marcus Hook at low water slack and apparently, pollution from downstream sources is not sufficient to deteriorate further the quality of the stream at Marcus Hook during the flood tide. Table 12 indicates the magnitude of the pollution load discharged in the upstream area from which the previous statement was deduced.

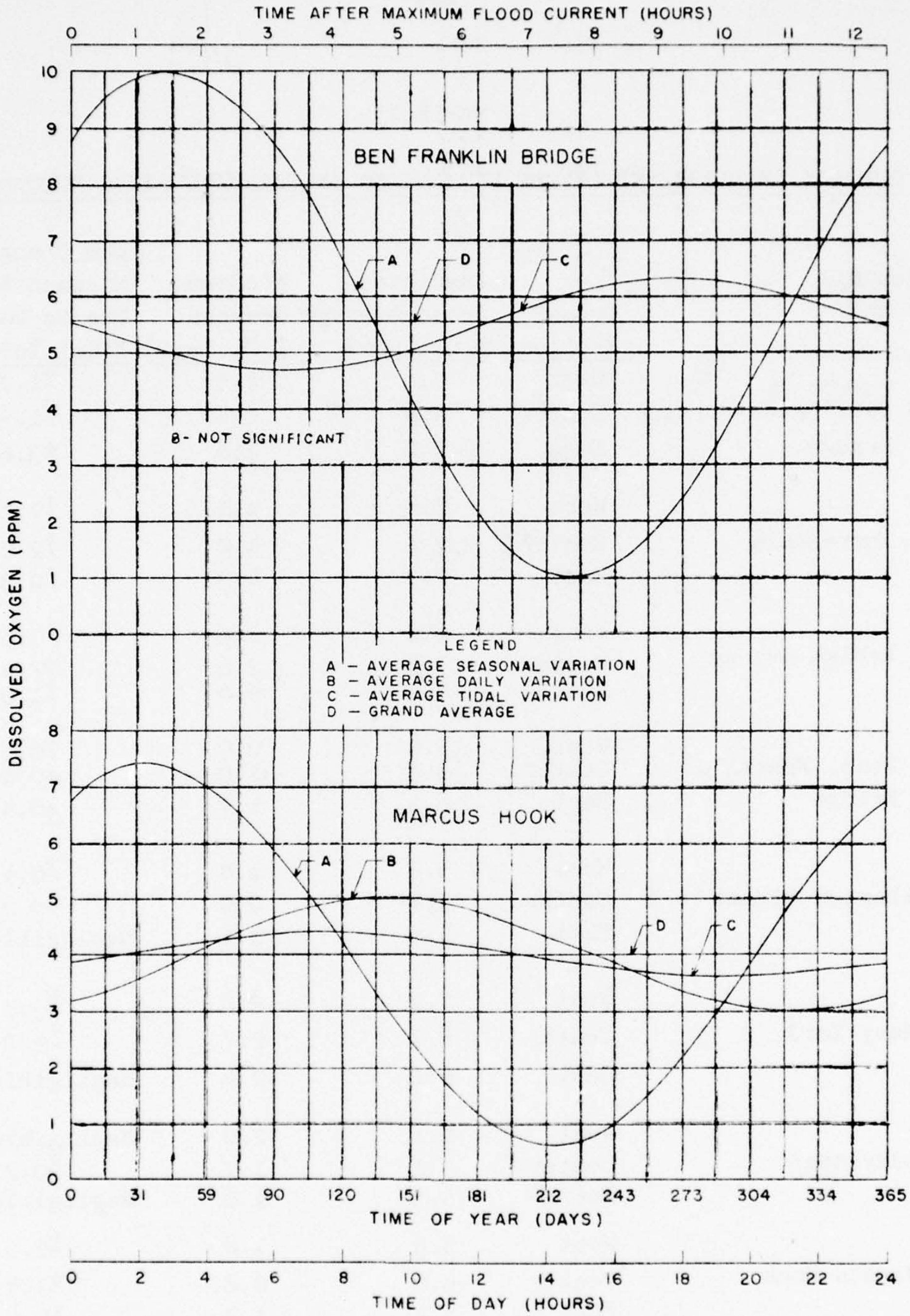
TABLE 15

SUMMARY OF DISSOLVED OXYGEN VARIATIONS IN DELAWARE RIVER ESTUARY

Station Mile Point and Name	Cross* Section	Predicted Grand Average D.O. (ppm)	Minimum Seasonal D.O. (ppm)	ppm Change in Minimum D. O. Due to Daily and Tidal Influences
	West	7.6	4.5	±1.7
117.8 Burlington-Bristol	Center	9.4	6.4	±1.3
Bridge	East	5.0	1.8	±3.6
	West	7.8	4.1	±1.1
110.4 Torresdale	Center	7.2	4.0	±2.2
	East	7.3	4.3	±0.5
	West	6.2	1.6	±0.6
102.2 Lehigh Avenue	Center	7.2	2.6	±2.4
	East	7.4	2.0	±1.0
	West	5.0	0.9	±0.6
100.5 Benj. Franklin	Center	5.5	1.0	±0.8
Bridge	East	6.2	1.7	±0.4
	West	5.2	1.0	±0.4
98.4 Wharton Street	Center	5.4	0.9	±0.2
	East	5.5	1.1	Negligible
	West	7.7	3.8	±3.8
93.2 Navy Yard	Center	6.7	2.7	±2.3
	East	6.1	2.4	Negligible
	West	6.1	2.8	Negligible
84.8 Eddystone	Center	5.1	1.7	±0.2
	East	5.3	1.8	Negligible
	West	5.3	1.8	±0.5
79.1 Marcus Hook	Center	4.0	0.6	±1.4
	East	4.4	1.2	±0.4
71.6 Cherry Island	Center	5.7	4.1	±2.2
66.8 New Castle	Center	5.4	4.3	±1.6

* Values are for surface only

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

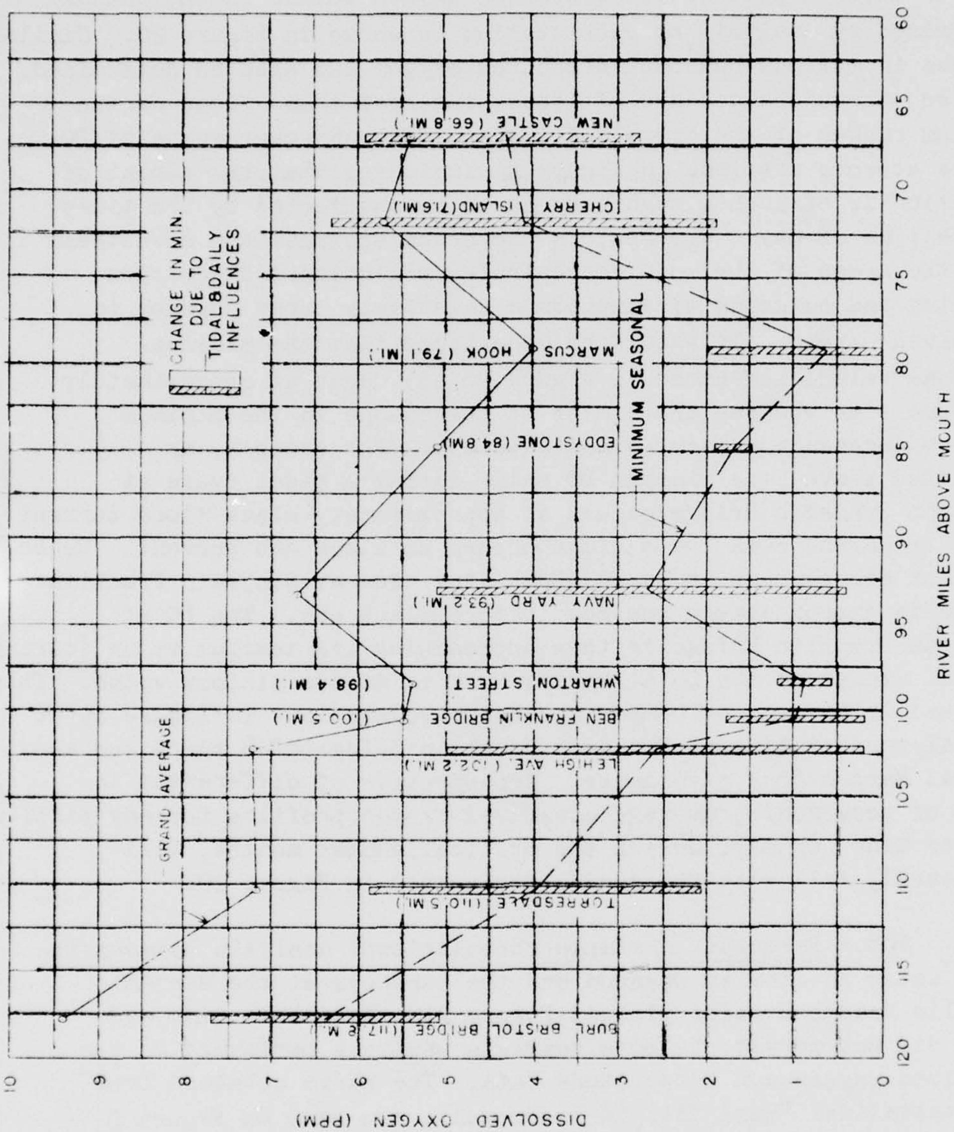
U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 19
TYPICAL DISSOLVED OXYGEN VARIATIONS
DELAWARE RIVER ESTUARY

107. A plot of the dissolved oxygen values in the channel determined by analysis at each station is shown in Figure 20. Similar changes in maximum seasonal dissolved oxygen can also be determined. However, these changes are of lesser interest than those of the minimum ranges of the dissolved oxygen. The narrower range of DO values at some stations in Figure 20 indicates that the amount of pollution is of such a magnitude as to be unaffected by the tides or the time of day. Whereas, in the areas upstream and downstream from the areas of the more concentrated pollutional discharges, incoming and outgoing tides produce relatively large changes in dissolved oxygen. It should be understood that the minimum seasonal values indicated in Figure 20 all occur at approximately the same time whereas the limits of the change in the minimum may not necessarily occur simultaneously. For example, as indicated above, the minimum DO value during a tidal cycle at Benjamin Franklin Bridge occurs at approximately slack flood current while at Marcus HOok the minimum occurs at slack ebb current. Hence, at slack ebb current at Marcus Hook, the tide at Benjamin Franklin Bridge is approximately one hour before slack ebb. The DO at Benjamin Franklin Bridge is then approaching its maximum value (during a tidal cycle) as the DO at Marcus Hook is at its minimum value. This can readily be seen by comparing these two stations in Figure 19 at a tidal current time at Benjamin Franklin Bridge of 8 hours and a time at Marcus Hook of 9 hours. Irrespective of differences in times of occurrence, average dissolved oxygen profiles for any particular time of tide, or day, during the critical summer months, will necessarily fall with the ranges designated in Figure 20.

108. Hardness A simple correlational analysis between the fresh water in-flow at Trenton and the hardness at the Benjamin Franklin Bridge Station yielded Figure 21. Available time and funds did not permit the more complete analysis performed on the dissolved oxygen and temperature data. The curve obtained from the statistical "best fit" is essentially the same as Figure 8, the hardness-flow relationship at Trenton. Apparently, the amount of hardness-forming constituents discharged by various municipalities and industries is of insufficient magnitude to be detected on a monthly average basis. Likewise, the total solids content of the estuary is sufficiently constant at this point and of a relatively small magnitude so as not to affect the hardness content.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 20

DISSOLVED OXYGEN PROFILE

DELAWARE RIVER ESTUARY

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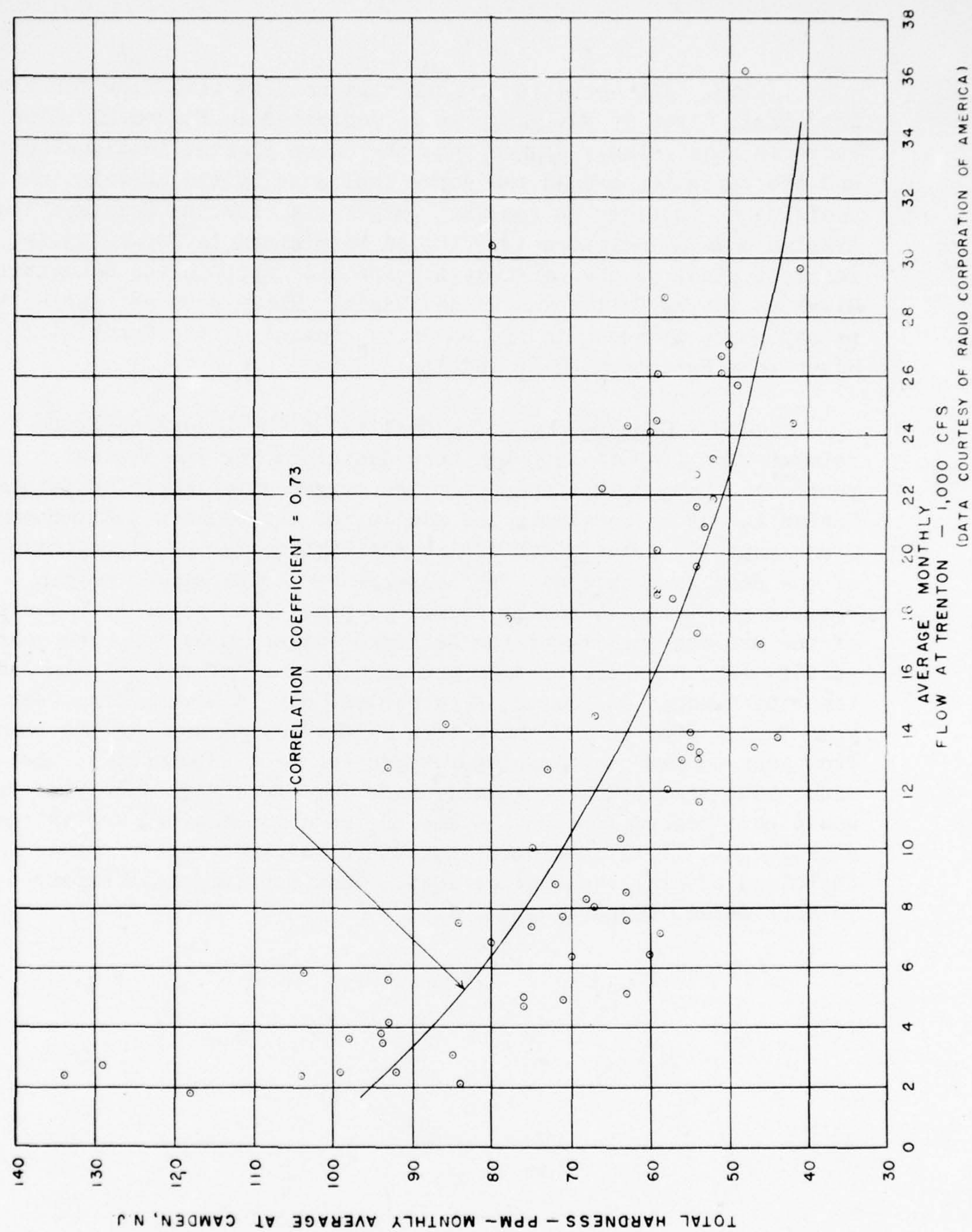


PART B — STREAM QUALITY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 21

HARDNESS — FLOW RELATIONSHIP

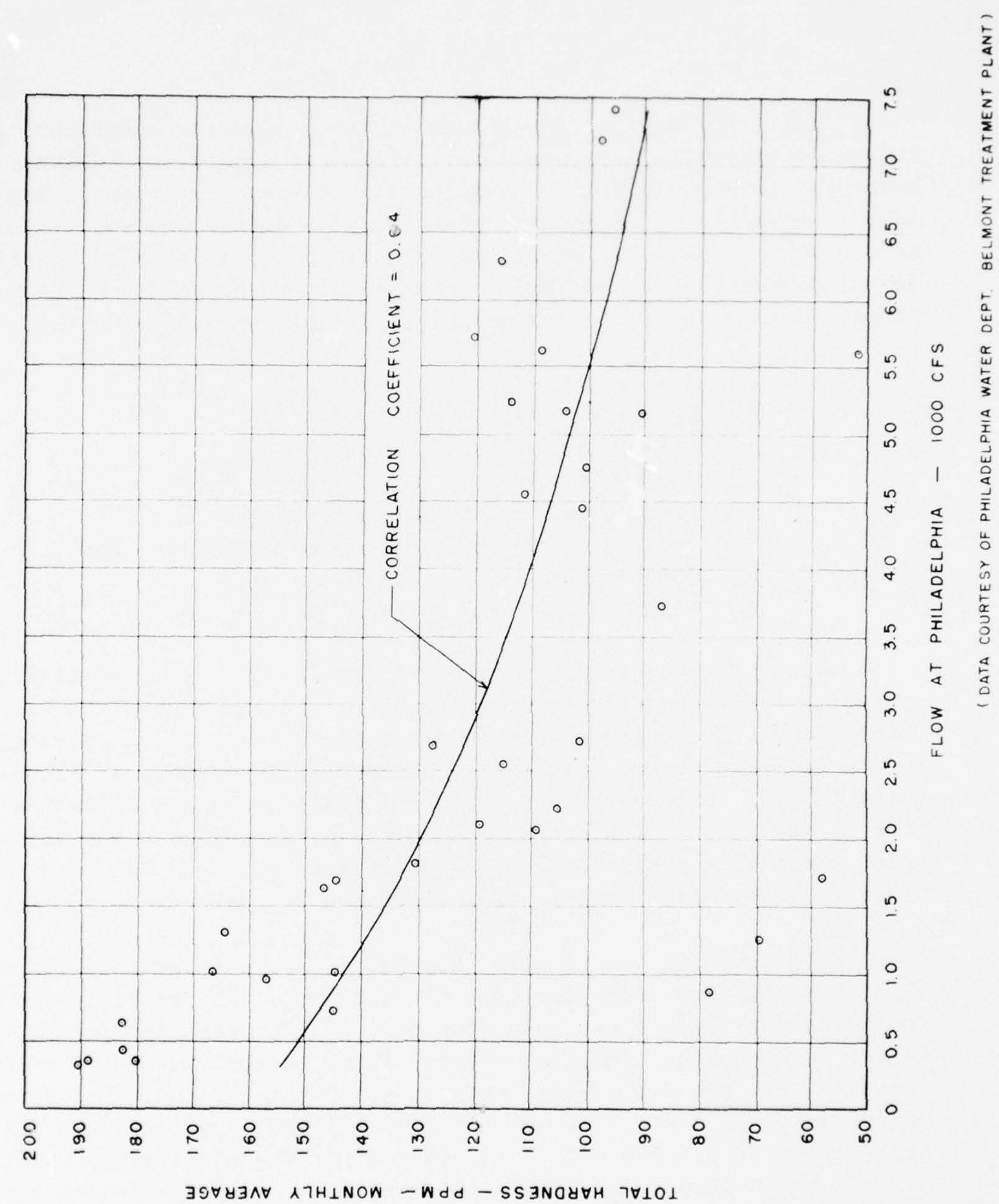
(1950 - 1955)

DELAWARE RIVER ESTUARY

109. The variation of hardness content with flow for the Schuylkill River at Philadelphia is indicated in Figure 22. The curve is considerably higher than the curve plotted in Figure 21; and the variation around the curve indicated by the correlation coefficient obtained is somewhat larger than for the Delaware itself. Available data indicates that the curve plotted in Figure 22 is fairly typical of the hardness-flow relationship in the Schuylkill River as far as Pottstown, Pennsylvania. There does not appear to be any sharp increase in the hardness content of the Schuylkill River from Pottstown to Philadelphia.

110. Conclusions The quality of the Delaware River estuary from 1949 to 1958 has been described for the average year using temperature and dissolved oxygen as primary indicators. Tables 14 and 15 summarize the quality of the estuary. Attachment 2 presents the details indicating the high degree of significance of the results obtained. The temperature and dissolved oxygen results in Tables 14 and 15 therefore provide an accurate description of the average quality of the Delaware estuary over the nine year period. The high correlation and significance of the results indicate that the changes in prevailing dissolved oxygen levels from year to year during 1949 to 1958 have been relatively minor. If the changes from year to year in dissolved oxygen had been substantial, the sinusoidal assumption originally made for the entire nine year period would have been disproven. Since the results obtained are extremely significant, it is concluded that there has been little change in dissolved oxygen levels since 1949. This conclusion is expanded in more detail in paragraph 119.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

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FIGURE 22

HARDNESS - FLOW RELATIONSHIP

SCHUYLKILL RIVER AT PHILA. PA.

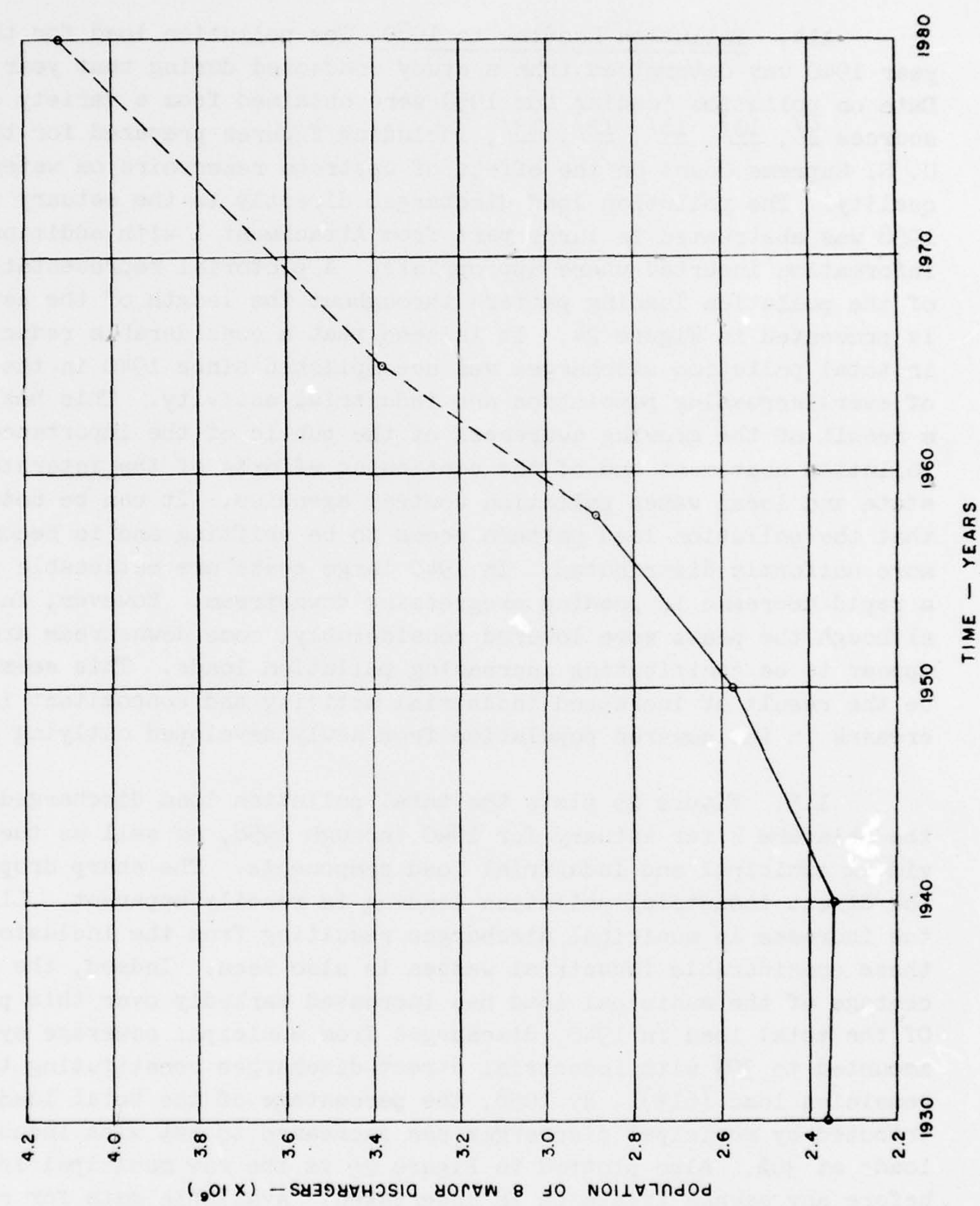
Future Trends

111. Population The trends in the population contributing to the municipal pollution load of the tidal portion of the Delaware River have been determined from an examination of eight principal areas. The data in Attachment 1 indicates that these areas account for approximately 94% of the total municipal pollution load discharged directly to the Delaware River estuary. These eight municipal discharge points originate from the following municipal or inter-municipal areas:

(a) Trenton, N. J.
(b) Levittown, Pa.
(c) Philadelphia, Pa.
(d) Camden, N. J.
(e) Darby Creek Joint Sewer Authority, Pa.
(f) Central Delaware County Sewer Authority, Pa.
(g) Chester, Pa.
(h) Wilmington, Del.

112. The population of these areas in 1950 was 2.58 million excluding Levittown, the Darby Creek S. A. and the Central Delaware County S. A. These three areas did not begin to discharge directly to the Delaware River until 1955. Estimates of populations subsequent to 1950 have been based as far as possible on the estimates made by the Office of Business Economics in Appendix B. For those areas where this was not possible, estimates have been made individually using Attachment 1, as a reference source.

113. Projection to 1980 Populations were determined for the eight areas listed above for 1930 through 1957. Projections were then made for these areas using the percent increases for the Sub-Region in which the area is located. These percent increases were obtained from the projections made by the OBE in Appendix B. Using an estimated population in 1957 of 2.88 million, application of percent increases yielded a 1965 population for the eight areas of 3.38 million and a 1980 population of 4.12 million. A plot showing the trend of the population for the eight critical areas is shown in Figure 23.



PART B — STREAM QUALITY

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FIGURE 23
TRIBUTARY POPULATION OF MAJOR AREAS IN DELAWARE RIVER ESTUARY

114. Pollution Loading to 1980 The pollution load for the year 1940 was determined from a study conducted during that year 9/. Data on pollution loading for 1950 were obtained from a variety of sources 9/, 10/, 11/, 12/, 13/, including figures prepared for the U. S. Supreme Court on the effect of upstream reservoirs on water quality. The pollution load discharged directly to the estuary in 1958 was abstracted in large part from Attachment 1 with additional information inserted where appropriate. A pictorial representation of the pollution loading pattern throughout the length of the estuary is presented in Figure 24. It is seen that a considerable reduction in total pollution discharges was accomplished since 1940 in the face of ever-increasing population and industrial activity. This has been a result of the growing awareness of the public of the importance of pollution abatement and of the continuing efforts of the interstate, state and local water pollution control agencies. It can be noted that the pollution load pattern seems to be shifting and is becoming more uniformly distributed. In 1940 large peaks are noticeable with a rapid decrease in loading progressing downstream. However, in 1957, although the peaks were lowered considerably, some downstream areas appear to be contributing increasing pollution loads. This seems to be the result of increased industrial activity and concomitant increases in the sewered population from newly developed outlying areas.

115. Figure 25 plots the total pollution load discharged to the Delaware River estuary for 1940 through 1958, as well as the individual municipal and industrial load components. The sharp drop in the direct industrial pollution loading is readily apparent. Likewise, the increase in municipal discharges resulting from the inclusion of these considerable industrial wastes is also seen. Indeed, the percentage of the municipal load has increased markedly over this period. Of the total load in 1940, discharges from municipal sewerage systems amounted to 39% with industrial direct-discharges constituting the remaining load (61%). By 1958, the percentage of the total load contributed by municipal discharges had increased to 64% with industrial loads at 36%. Also plotted in Figure 25 is the raw municipal load before any sewage treatment is undertaken. Available data for raw loadings in 1958, indicated a total of 708,000 #BOD/day which for the estimated population of 2.88 million in the eight critical areas results in an average per capita contribution of about 0.24 #BOD/day as

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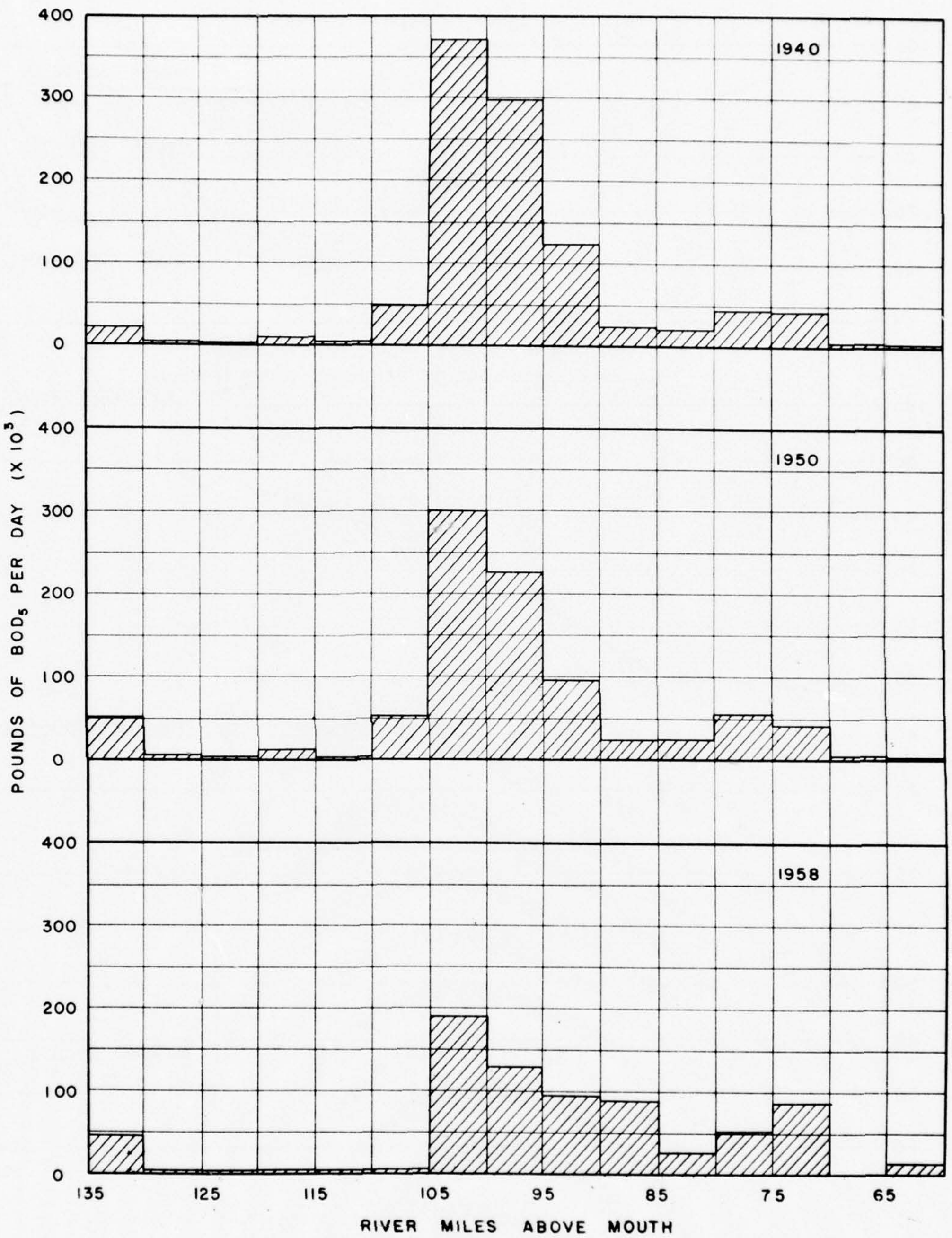

PART B – STREAM QUALITY

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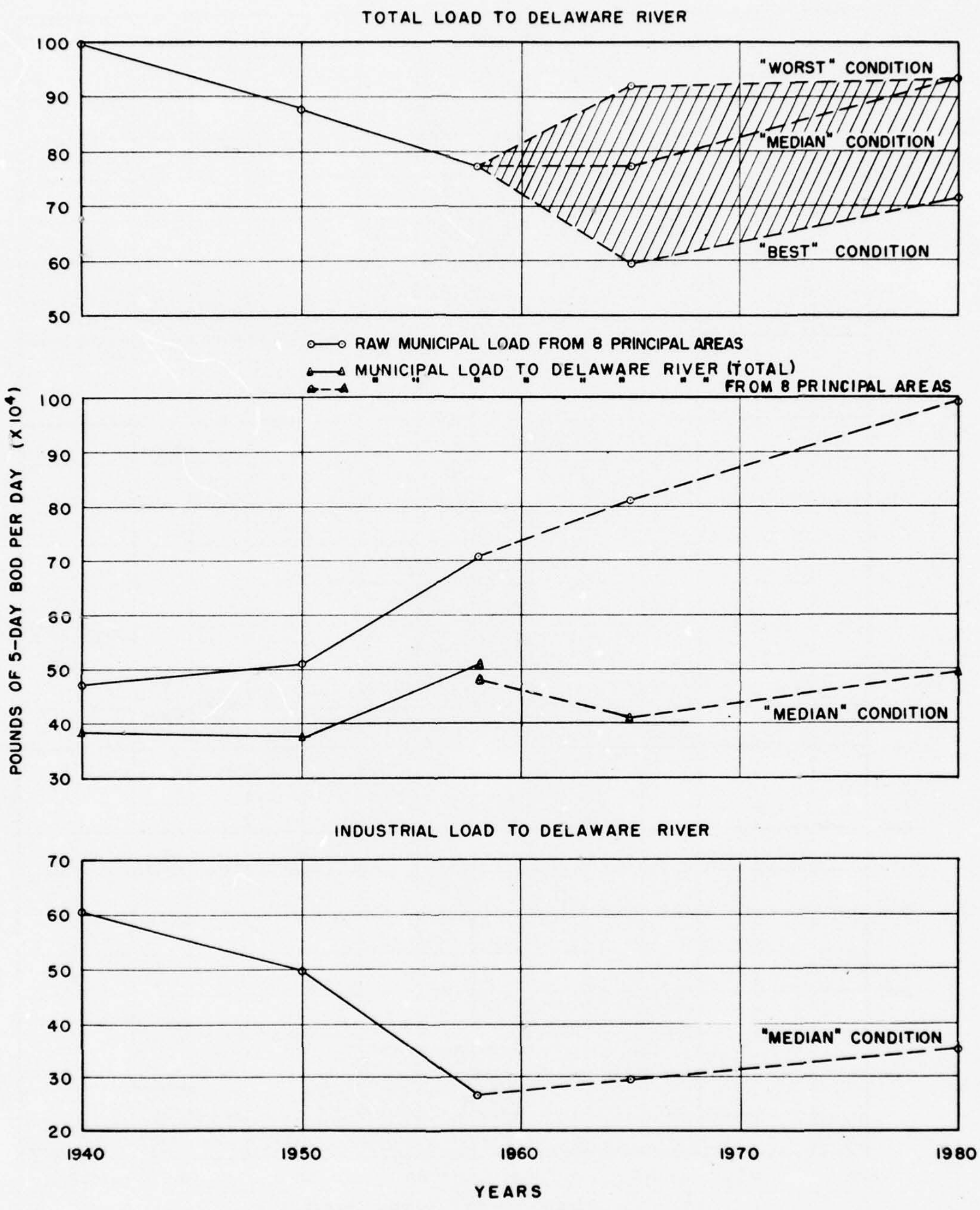
FIGURE 24
POLLUTION LOAD PROFILES
DELAWARE RIVER ESTUARY

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART B – STREAM QUALITY

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FIGURE 25
POLLUTION LOAD
DELAWARE RIVER ESTUARY

compared with a loading of approximately 0.20 #BOD/day in 1940. A possible increase in this per capita loading figure may occur due to the increased use of household garbage grinders, but for purposes of future estimates any such potential increase has been taken into account in the future ranges of removal of pollution loadings. The present composition of the sewage being treated by the eight principal areas will remain essentially the same, since a large majority of the industries in the area are being served by the municipal plants. Indeed, operating figures from the three Philadelphia sewage treatment plants indicates a raw per capita loading of 0.17 #BOD/day, the "rule of thumb" used by sanitary engineers for many years. The difference between this figure and the 0.24 #BOD/day obtained above is due primarily to the sewage being treated at the Camden and Wilmington plants.

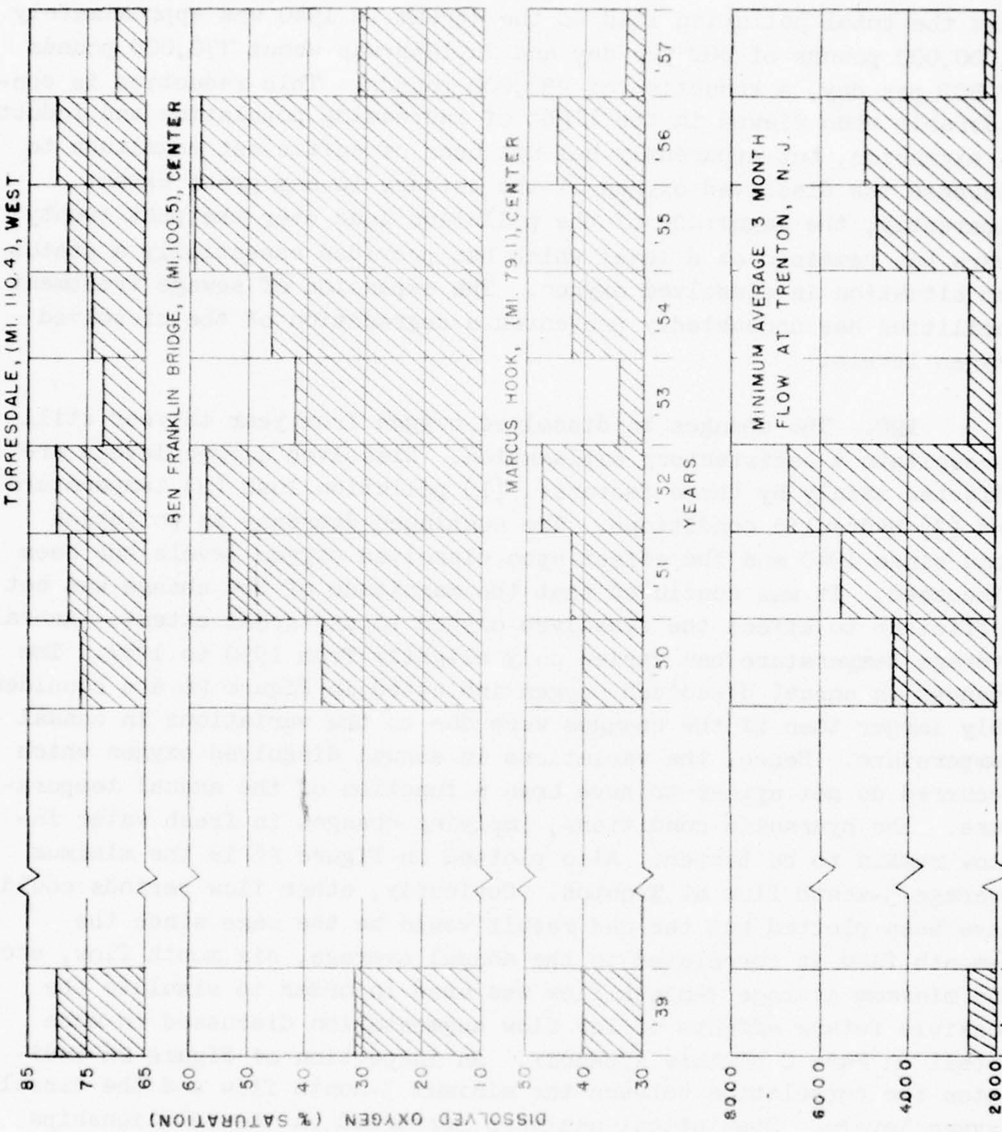
116. Applying a per capita loading of 0.24 #BOD/day to the projected populations for the eight principal areas resulted in the raw municipal load to be expected from these areas in 1965 and 1980, as shown in Figure 25. Projections were not made for a raw industrial load due to the lack of sufficient data needed for an accurate estimate. Hence, industrial loadings to the estuary have been assumed to increase linearly at approximately the same slope as the population increase shown in Figure 23. Following the determination of the raw municipal pollution load expected in the eight critical areas, an assumption must be made regarding the efficiency of treatment processes in removing this pollution. In 1958, the raw municipal load prior to any sewage treatment from the eight principal areas totaled about 708,000 #BOD/day. Of this total, 68% (475,000 #BOD/day) reached the Delaware River for an overall removal of about 32%. The 475,000 #BOD/day discharged to the river includes those sections within the eight areas which were not served by sewage treatment plants. The actual removal efficiency of the treatment plants, i.e., the amount of load removed from the total load entering the plants, was about 45%. However, as far as the load to the River is concerned, the 475,000 #BOD/day which was discharged represents a reduction of 32% of the potential total load which might have reached the stream. Projections have been made under three general assumptions:

(a) 50% removal in 1965 and 1980; a "median" condition
(b) 30% removal in 1965 and 50% removal in 1980; a "worst" condition
(c) 70% removal in 1965 and 1980; a "best" condition

117. Applying these removal factors to the raw pollution load to be expected in 1965 and 1980 and adding the projected industrial load indicated in Figure 25 and applying a percentage (10% for 1965 and 1980) for the area not covered by the eight principal locations results in the range of pollution loadings to be expected in 1965 and 1980. For purposes of further discussion regarding the effect of pollution loadings on stream quality, the "median" pollution load has been used. It should be remembered however, that the load may be greater or lesser and that resulting stream quality may likewise be affected to a greater or lesser extent.

118. In conclusion, it is anticipated that the present (1958) level of pollution will continue until approximately 1965 at which time a gradual increase in loading will begin to occur. By 1980, it is expected that the level of pollution will be slightly higher than that in 1950. This projection of future loading conditions is utilized in the description of expected water quality conditions in 1965 and 1980.

119. Stream Quality to 1980 It has been pointed out previously in Paragraph 110 that since the analysis performed on the data collected from 1949 to 1958 was highly significant, it appears that little change in dissolved oxygen had occurred from year to year during this period. Apparently, the reduction in pollution load which occurred during 1949 to 1958 was not sufficient to materially affect the dissolved oxygen of the estuary. Changes in dissolved oxygen undoubtedly did occur from year to year and an indication of these changes is presented in Figure 26. This Figure is a plot of the annual average dissolved oxygen in per cent saturation for three stations for the years 1950 to 1957 with results also included for 1939. The data for 1939 is from the Corps of Engineers' survey conducted during that year. 4/ The dissolved oxygen in per cent saturation has been used to document changes from year to year in order to utilize the 1939 results as a basis for comparison since dissolved oxygen values in terms of parts per million were not available. Although the changes in dissolved oxygen from year to year varied from a maximum of 28% at Benjamin Franklin Bridge to a minimum of 10% at Torresdale, it is important to note that there has been no significant straightline trend over these years. Annual average dissolved oxygen levels at all three stations fell to as low a level during 1957 as during 1939. It has been indicated previously



PART B – STREAM QUALITY

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FIGURE 26
YEARLY TREND IN DISSOLVED OXYGEN
DELAWARE RIVER ESTUARY

that the total pollution load to the stream in 1940 was approximately 1,000,000 pounds of BOD per day and in 1958 was about 770,000 pounds of BOD per day, a reduction of 230,000 pounds. This reduction is considerable when viewed in the light of increasing population and industrial expansion, but apparently has not been of sufficient magnitude to increase the dissolved oxygen of the estuary to any great extent. Apparently, the magnitude of the pollution load over the past twenty years has remained at a level which has provided essentially a status quo situation in dissolved oxygen. The expansion of sewage treatment facilities has undoubtedly prevented a degradation of the dissolved oxygen levels.

120. The changes in dissolved oxygen from year to year still necessitate a satisfactory explanation. Dissolved oxygen levels are affected mainly by three factors: (1) pollution load (2) temperature and (3) hydraulic conditions. The continued decrease in pollution load since 1940 and the effect upon dissolved oxygen levels has been discussed. It was concluded that the magnitude of the change was not sufficient to affect the dissolved oxygen to any great extent. Annual average temperature has varied only slightly from 1950 to 1957. The changes in annual dissolved oxygen indicated in Figure 26 are considerably larger than if the changes were due to the variations in annual temperature. Hence, the variations in annual dissolved oxygen which occurred do not appear to have been a function of the annual temperature. The hydraulic conditions, implying changes in fresh water inflow remain to be tested. Also plotted in Figure 26 is the minimum average 3-month flow at Trenton. Obviously, other flow periods could have been plotted but the end result would be the same since the 3-month flow is correlated to the annual average, six month flow, etc. The minimum average 3-month flow was used in order to simulate the possible future effects of low flow augmentation discussed in more detail in Part C of this Appendix. An inspection of Figure 26 indicates the correlation between the minimum 3-month flow and the dissolved oxygen levels. Statistical analyses performed on the relationships between the dissolved oxygen levels at each station and the minimum 3-month flow indicated correlation coefficients of 0.75 at Torresdale, 0.75 at Benjamin Franklin Bridge and 0.61 at Marcus Hook. These results are within a 10% level of significance. Hence, the "odds" are greater than 90 out of 100 that the relationship between the dissolved

oxygen and the minimum 3-month flow is an accurate one and not due to chance alone. This does not imply that some other multiple or fraction of the 3-month period would correlate at the same level of significance. Other flow periods may bear a relationship to the annual dissolved oxygen to a greater or lesser degree. However, the relationship between the annual dissolved oxygen and the minimum average 3-month flow is adequately established. The conclusion which may be drawn from this fact is that the annual average dissolved oxygen is largely a function of some flow period and is definitely a function of the minimum average 3-month flow. It appears then that the changes in prevailing annual average dissolved oxygen levels during 1950-1957 in the Delaware River estuary were determined to a large degree by the variations in the amounts of fresh-water inflow across any one year. Also, from the projected pollution load in 1980, (which is anticipated to be slightly higher than that in 1950) it is expected that this relationship will be maintained throughout this future period.

121. The above reasoning regarding annual average dissolved oxygen levels can logically be extended to dissolved oxygen levels <u>within</u> any given year. The variations in water temperature within any year during the 1950-1957 period although considerable (see Table 14) have been relatively constant from year to year. Hence, although high water temperatures will increase the rate of utilization of oxygen by a pollution load thereby decreasing the amount of dissolved oxygen, this decrease will be approximately the same amount each year. (This assumes no significant change in the variations of water temperature as may result from future high temperature discharges). Also, the total pollution load to the stream remains fairly constant within any year, thereby affecting the variation in dissolved oxygen only to a minor extent. The variations in fresh water inflow are considerable within any one year. The effect of flow on the annual average dissolved oxygen has previously been established. With this relationship determined, it is logical to conclude that if some fresh water flow period affects the annual average dissolved oxygen it affects the seasonal variation in dissolved oxygen. If the flow did not affect the seasonal variation, it could not affect the annual average.

122. The above discussion can be summarized as follows:

(a) The pollution load discharged into the Delaware estuary since 1940 has established the overall level of the dissolved oxygen in the estuary.
(b) The changes in annual average dissolved oxygen levels from 1950-1957 have been influenced primarily by the fresh water inflow.
(c) The variation of dissolved oxygen within any year about the prevailing level originally established by the magnitude of the pollution load is primarily a result of temperature and flow. The detailed extent of the contribution to this variation by either temperature or flow is not independently known.

123. From the above discussions, the following conclusions may be drawn:

(a) From 1958-1980 it is expected that the growth in population and industry in the area surrounding the estuary will substantially increase the potential pollution load. It is also anticipated that the increased interception of waste and increased efficiency of treatment will increase the present level of about 30% removal of the potential pollution load to 50% by 1965 and holding at this level until 1980. The resultant pollution load to the stream including municipal and industrial discharges is expected to remain at the present level until 1965 at which time the load will increase gradually to a level in 1980 which will be slightly higher than the level in 1950.
(b) The mean dissolved oxygen level during 1950-1957 was a result of the pollution load to the stream which existed during this period. For the pollution loading anticipated for the period ending 1980 (conclusion (a)), it is not expected that this mean dissolved oxygen level will be materially affected.

(c) The year-to-year changes in average annual dissolved oxygen which occurred during 1950 to 1957 were primarily a result of the changes in fresh water inflow. Since it is anticipated that the mean dissolved oxygen level which occurred during 1950-1957 will not be materially affected by the future pollution load (conclusion (b)), it is concluded that any future changes in annual average dissolved oxygen will be due primarily to changes in fresh water inflow.

(d) Since the changes in annual average dissolved oxygen during 1950-1957 were due in large part to changes in fresh water inflow (conclusion (c)), the changes in dissolved oxygen <u>within</u> any year during 1950-1957 were also a result of changes in fresh water inflow as well as changes in water temperature.

(e) From conclusion (c), which indicates that the future changes in annual average dissolved oxygen will be mainly a result of fresh water inflow, and from conclusion (d), which indicates that the changes in dissolved oxygen <u>within</u> the average year during 1950-1957 were a result of changes in fresh water inflow and temperature, it is expected that until 1980 the changes within a year in dissolved oxygen will be primarily a result of the changes in fresh water inflow and water temperature.

(f) The changes in dissolved oxygen within the average year during 1950-1957 have been described using statistical methods. Since these changes in dissolved oxygen were a result of the same factors which are expected to influence the changes in dissolved oxygen within future years (conclusion (e)), it is expected that the changes that have occurred during 1950-1957 will remain essentially the same through the period ending in 1980. It is therefore anticipated that the description of dissolved oxygen within the average year during 1950-1957 will continue to be applicable until 1980.

124. Projections to 2010 The estimates of pollutional loads and resulting water quality, 50 years hence, are subject to extreme variations resulting from many unknowns and lack of sufficiently long-term past data. Possible future changes in sewage treatment technology may entirely vitiate assumed removal efficiencies and consequently the pollutional load to the stream. Also, considering the removal efficiency of sewage treatment plants to have a 15-20 years design life, it must be assumed that the various communities will periodically replace or enlarge the plant to increase its removal efficiency. The final estimates of pollutional loads should therefore be viewed with all of these basic assumptions in mind and wide changes may be expected.

125. Pollution Load in 2010 Projections of the population and the total pollution load to the Delaware estuary in 2010 can be made on the same basis as described previously. Hence, the raw municipal pollution load, i.e., the potential load which would enter the stream were it not treated is estimated from the eight principal areas, mentioned previously. This load is estimated to reach about 1,300,000 #BOD/day in 2010. If a 50% removal of this load can be accomplished by sewage treatment, the municipal load to the stream in 2010 will be about 650,000 #BOD/day. However, with the increasing emphasis on pollution abatement and more important on sewage treatment research, the overall efficiency of removal of the municipal load may approach 70%. In this case the municipal load to the stream in 2010 would be about 400,000 #BOD/day. Hence, in 2010, it is estimated that the municipal pollution load entering the estuary from the eight principal areas would be between 400,000 #BOD/day and 650,000 #BOD/day.

126. To the municipal pollution load to the stream must be added the discharge of the industrial load which is not served by municipal sewage treatment plants. Again, the load contributed by industries discharging directly to the estuary has been assumed to increase linearly with increasing population. By 2010, it is estimated that the industrial load to the estuary will be between 500,000 #BOD/day and 750,000 #BOD/day.

127. The total load, both municipal and industrial to the estuary in 2010 is therefore estimated to be between 900,000 #BOD/day and 1,400,000 #BOD/day depending upon the extent of removal efficiencies. It is seen that with 70% removal efficiency, a status quo situation with regard to pollution load will exist throughout the period from 1980 to 2010. In order to approximate the total pollution load to the estuary in 1958, 80% removal of the municipal load would have to be accomplished assuming the direct industrial load at 500,000 #BOD/day. If pollution abatement measures are maintained at approximately present levels, the total load in 2010 to the estuary will be about 1,400,000 #BOD/day or more than 50% greater than the 1958 level.

128. Stream Quality in 2010 The direction of change in water quality will closely parallel the direction of change in the pollution load. With a pollution load 50% greater than the 1958 load, it can be expected that quality conditions will deteriorate significantly and will probably approach the conditions which existed in 1940. Likewise for a pollution load of 900,000 #BOD/day in 2010 (essentially the same level as in 1950), water quality conditions may be expected to be approximately the same as in 1950. However, with increased technical productivity and the further extension of the present complex industrial technology, the BOD may not be the most important measure of industrial load. Rather, the newer complex organic chemical constituents may assume greater importance in the assessment of future stream quality conditions.

129. Summary of conditions in 2010 It is estimated that the total pollution load to the estuary in 2010 will be between 900,000 #BOD/day and 1,400,000 #BOD/day. The lower figure assumes that a significant increase in pollution removal efficiency measures will be accomplished. The resulting water quality from the load estimated in 2010 will be between the conditions which existed in 1940 and those which existed in 1950 although increasing industrial technologies may create quality problems heretofore unrecognized. Should this substantial pollution removal not be accomplished, the quality of the estuary will progressively deteriorate to the level which existed in 1940. However, the efforts of the various water pollution control agencies which have been so effective in the past can be assumed to continue and it does not appear that quality conditions will be allowed to retrogress to the level of 20 years ago.

PART C

EFFECTS OF COMPREHENSIVE PLAN

PART C

Effects of Comprehensive Plan

Contents

SECTION I - FOREWORD

Scope

1. Purpose The purpose of this Part of Appendix C is to indicate the anticipated effects on stream quality during and following the construction of the proposed system of reservoirs in the Delaware basin. This Part is intended to serve as a guideline for future detailed studies of the various impoundments and their effects on the quality of the stream.

2. Organization The following provides a general evaluation of stream quality changes both from individual reservoirs and from intregated systems of reservoirs, based on the information and conclusions from Part A, Municipal and Industrial Water Use and Part B, Stream Quality. The background material providing detailed descriptions of the individual sites, future water demands and other pertinent information has been obtained primarily from the other Appendices of the Corps of Engineers' report. Benefits and costs, which result from changes in stream quality, are discussed and where indicated further detailed evaluations are presented.

3. Acknowledgements The cooperation and assistance given by the following agencies is gratefully acknowledged:

Federal Agencies:
- Department of the Army
- Corps of Engineers District, Philadelphia

Interstate Agencies:
- Interstate Commission on the Delaware River Basin

State Agencies:
- New York
  - Department of Health
  - Water Pollution Control Board
- New Jersey
  - Department of Health
- Pennsylvania
  - Department of Health
- Delaware
  - Water Pollution Commission

SECTION II - INTRODUCTION

General

4. Subdivision of projects The projects (Figure 1) evaluated in this Part were subdivided into two groups:

Group I - Major control projects

Group II - Limited development projects

5. The eleven major control projects in Group I will constitute the largest regulation of water resources. The projects proposed are multi-purpose impoundments and include provision for flood control, water supply, hydropower, silt control and recreation. These projects of necessity require detailed evaluation with respect to their effects on stream quality.

6. A total of eight projects were considered in Group II. These projects will not substantially affect the flow regime of the respective streams and therefore only a general evaluation of the quality to be expected in the impoundments is made.

7. Figure 1 indicates the location of the projects and Table 1 presents a tabular description of the various impoundments. A more complete description of each of the projects is given in Appendix U.

Impoundments and Stream Quality

8. The retention of water during high flow periods and subsequent release during low flow periods influences the quality of the water in varying degrees. Also, storage sites constructed primarily for recreation, which have no effect on the flow regime of the stream, may change the quality of the incoming water. The problem then is three-fold: (a) the effect on quality of storing water for relatively long periods of time in deep pools; (b) the effect of the multiple purpose use of the water in the reservoir and (c) the subsequent release of this water during periods of low flow and the

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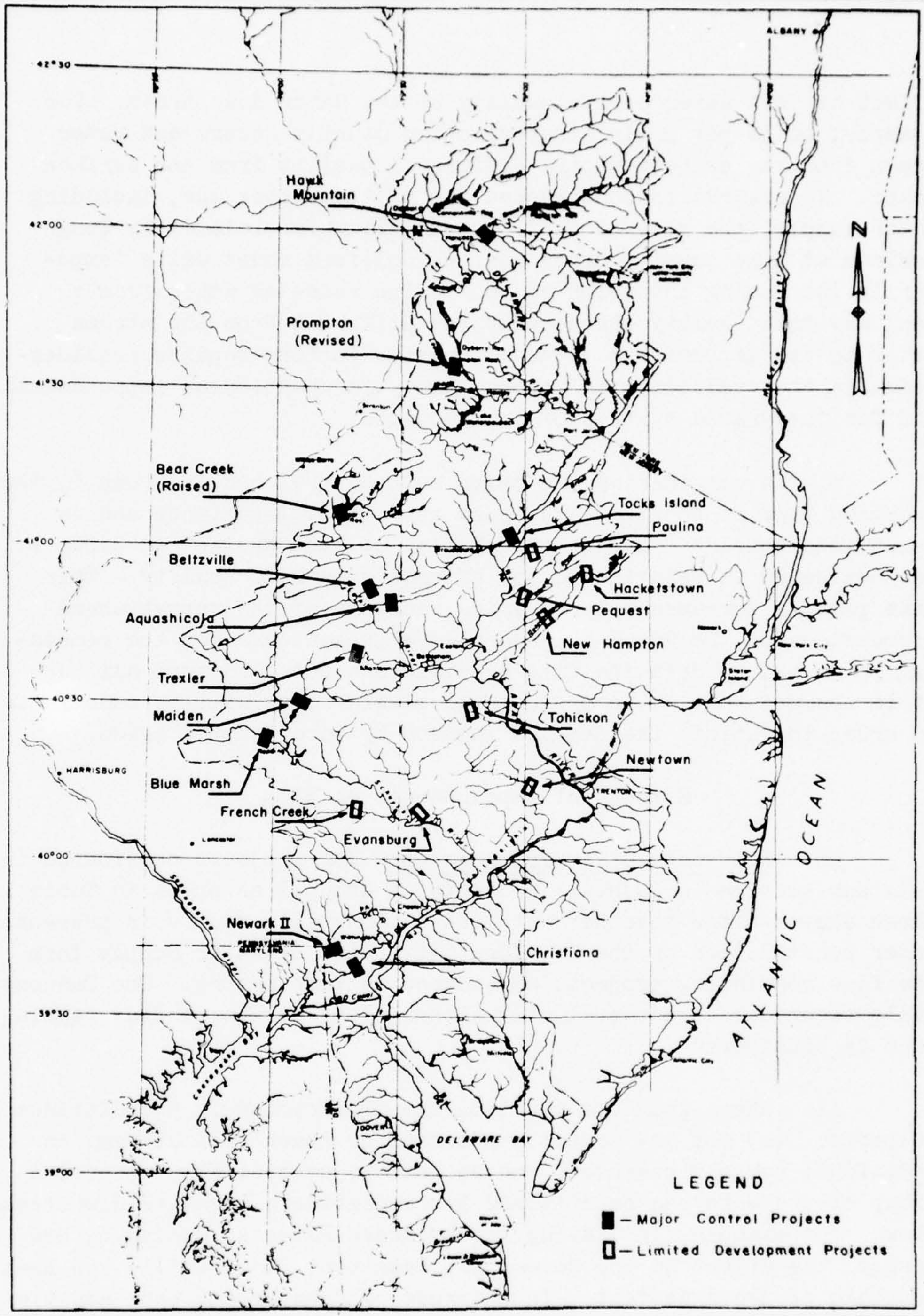

PART C - EFFECTS OF COMPREHENSIVE PLAN

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FIGURE 1

PROPOSED PLAN OF PROJECT DEVELOPMENT

effect of this water on the quality of the water downstream. For example, in deeper pools stratification usually occurs and water drawn from the deepest depths differs in quality from the surface water. In reservoirs constructed for multi-purpose use, including water supply, the retention of incoming flow for relatively long periods of time usually decreases the coliform count while temporarily increasing the color content. The released water from a pool may have quality characteristics different from the stream prior to its impoundment. Thus, numerous factors require consideration in the evaluation of water quality for particular impoundments and for integrated systems of impoundments.

9. In considering the major control projects in Group I, the proposed time of construction is of the utmost importance and is taken into account. Hence, the phasing of each project in Group I is considered in relation to the effects on stream quality. This time phasing pervades all remaining sections of the report where discussions of the Group I projects are presented. For the remaining projects, no definite time schedule has been proposed although it is assumed that these projects or similar ones will be constructed in order to satisfy the demands imposed by water supply needs.

Effects of Impoundments on Flow

10. Flow regulating impoundments The projects considered in this sub-section include all projects in Group I as shown in Table 1. These eleven sites together with the Cannonsville reservoir presently under construction by the New York City Board of Water Supply form the flow regulating projects considered in this report. The Cannonsville reservoir is not evaluated although its effect on flow regulation is considered.

11. These projects regulate the flow regime in two distinct respects: (a) for any particular stream or reach of a stream, an individual dam and reservoir can be used to control flow and (b) a group of projects can be utilized to cumulatively regulate downstream flow. For example, in viewing the Delaware River at Montague, New Jersey, the effect of the Neversink, Pepacton, Cannonsville and Hawk Mountain projects is felt. In progressing downstream, each additional

TABLE 1

PERTINENT DETAILS
OF
PROPOSED PROJECTS

	Name	Stream	Volume* (Acre-feet)	Pool Depth at Dam* (Feet)
Group I:	Tocks Island	Delaware River	490,000	110
	Hawk Mountain	E. Branch Del. R.	293,000	150
	Maiden	Maiden Creek	76,000	80
	Bear Creek**	Bear Creek	72,000	185
	Beltzville	Pohopoco Creek	41,200	120
	Christiana	Christina River	37,000	45
	Prompton**	Lackawaxen River	31,400	90
	Newark	White Clay Creek	31,000	80
	Aquashicola	Aquashicola Creek	25,000	65
	Trexler	Jordan Creek	25,000	90
	Blue Marsh	Tulpehocken Creek	16,000	50
Group II:	Newtown	Neshaminy Creek	62,000	80
	Paulina	Paulins Kill	55,000	120
	New Hampton	Musconetcong River	44,000	85
	Pequest	Pequest River	41,000	90
	Tohickon	Tohickon Creek	31,500	85
	French Creek	French Creek	27,000	80
	Evansburg	Skippack Creek	25,000	70
	Hackettstown	Musconetcong River	23,000	55

* Excluding flood control storage, but including inactive storage

** Modification of existing project

Note: Pool depths are measured from approximate valley floor elevations rounded to nearest 5 feet.

project either on the main stream or a tributary, contributes its flow regulating potential. Tables 2 and 3 indicate both of these effects for the Delaware, Lehigh and Schuylkill Rivers. Also included in these tables is the year during which the project is proposed to be constructed in order to meet the increasing water supply needs of the basin. For additional details regarding the computation of phasing, reference should be made to Appendix P, Gross and Net Water Needs and Appendix Q, Formulation of Plan of Development. The flows indicated in Tables 2 and 3 are minimum sustained yields i. e. with the project capacities indicated in Appendix U. Each impoundment is designed to maintain the gross yield shown under severe drought conditions.

12. Inspection of Tables 2 and 3 indicates that the major portion of low flow augmentation will occur during the period ending approximately 1980. For the Lehigh River at Bethlehem, the total regulation is proposed to be available by 1989 when it is anticipated that the present natural minimum flow will be increased from 320 cfs to 714 cfs, an increase of 123%. For the Delaware River at Trenton (Table 3), an 80% increase in the minimum flow is anticipated by about 2000, with 70% of the increase occurring by about 1980. Therefore, the sustained yield at Trenton in 1981 of 4,063 cfs, resulting from the proposed system of reservoirs, will be about 86% of the maximum sustained yield anticipation for 2002 following the completion of all of the proposed projects. The augmentation of low flow resulting from the proposed integrated system of reservoirs will be most substantial during the period ending in about 1980. Subsequently, the implementation of the remaining projects in the plan will add a lesser contribution toward the augmentation of minimum flows.

TABLE 2

LOW FLOW REGULATION-MAJOR TRIBUTARIES

LEHIGH RIVER

Project	Proposed Comple-tion Date	Cubic Feet per Second: Minimum Monthly Flow at Site	Gross Yield	Flow Increment from Project	Minimum Flow Lehigh River at Bethlehem, Pa.
					320
Beltzville	1965	25	105	80	400
Trexler	1972	13	68	55	455
Aquashicola	1981	15	78	63	518
Bear Creek	1989	72	268	196	714

SCHUYLKILL RIVER

Project	Proposed Comple-tion Date	Cubic Feet per Second: Minimum Monthly Flow at Site	Gross Yield	Flow Increment from Project	Minimum Flow Schuylkill R. at Philadelphia, Pa.
					350
Blue Marsh	1969	45	110	65	415
Maiden	1982	42	176	134	549

NOTE: While indicated minimum flow can be made available if needed as of the completion dates shown, operation of reservoirs for water supply demands may delay realization of full minimum flows to a later date.

TABLE 3

LOW FLOW REGULATION

DELAWARE RIVER

Project	Proposed Completion Date	Minimum Monthly Flow at Site (Cubic Feet per Second)	Gross Yield (Cubic Feet per Second)	Flow Increment from Project (Cubic Feet per Second)	Minimum Flow at Trenton New Jersey (Cubic Feet per Second)
					2,615 1/
Cannonsville	1965	-	-	225	2,840
Beltzville	1965	25	105	80	2,920
Trexler	1972	13	68	55	2,975
Prompton	1974	9	66	57	3,032
Tocks Island	1975	1,857 2/	2,825	968	4,000
Aquashicola	1981	15	78	63	4,063
Bear Creek	1989	72	268	196	4,259
Hawk Mtn.	2002	130	652	465 3/	4,724

1/ Includes effects of Pepacton and Neversink.

2/ Includes effect of Prompton and NYBWS reservoirs.

3/ Flow increment below Tocks Island. (At Hawk Mtn. dam site flow increment = 552 cfs)

NOTE: While indicated minimum flow can be made available if needed as of the completion dates shown, operation of reservoirs for water supply demands may delay realization of full minimum flows to a later date.

SECTION III - EXPECTED WATER QUALITY IN PROPOSED IMPOUNDMENTS

General

13. Reservoir uses It is of importance to consider here the various uses for which an impoundment is intended, since the quality of the water in the reservoir will determine the extent to which these uses may be implemented. The impoundments outlined in the preceding paragraphs will be considered in accordance with their proposed uses (Appendix Q). Throughout this section, the proposed utilization of each reservoir has been considered to constitute a potential use in the immediate vicinity of the project. The effect of the quality of water released from storage on downstream uses will be considered in detail in Section IV - Effects of Proposed Impoundments on Stream Quality.

14. In general, detention in a reservoir results in changes in water quality. One of the more important changes is in water temperature. Usually, the changes are more pronounced in deep pools, where the depth at which water is withdrawn can alter the temperature structure in the reservoir to a considerable extent. The general mechanisms at work in establishing the temperature of the water in the reservoir are presented below.

15. Temperature stratification For purposes of this discussion an evaluation will be made of the temperature variations at the dam, the point at which withdrawals are usually made. Consider a typical impoundment with a depth of approximately 150 feet at the face of the dam and with a high-level intake. During the late winter, the pool waters will usually have an almost uniform temperature from top to bottom of approximately 10°C. However, when the reservoir temperature falls to 40°C and much water enters the reservoir with a temperature less than 4°C, the point of maximum density, winter stratification will occur with the 4°C. water in the surface layers and the colder water in the bottom layers. With the advent of warmer weather, because of higher temperature and lower density, the incoming flow tends to float above the cooler waters, and by the beginning of March temperature stratification commences. As the incoming flow becomes

progressively warmer, stratification becomes more distinct. By approximately June or July, three definite zones have been established. The upper zone, or epilimnion, contains the water of highest temperature. The water temperature in the middle zone or thermocline decreases rapidly with small increases in depth. The lower zone, the hypolimnion, contains the coldest water. For continuous drawoffs from a high intake in the dam, the temperature of the discharge closely parallels that of the incoming water and may be slightly higher due to warming by the sun. Essentially all the water which is released (assuming a relatively constant pool level) is obtained from the epilimnion. The water in the hypolimnion (lowest zone) warms very slowly during the summer with an increase of 2°C - 3°C.

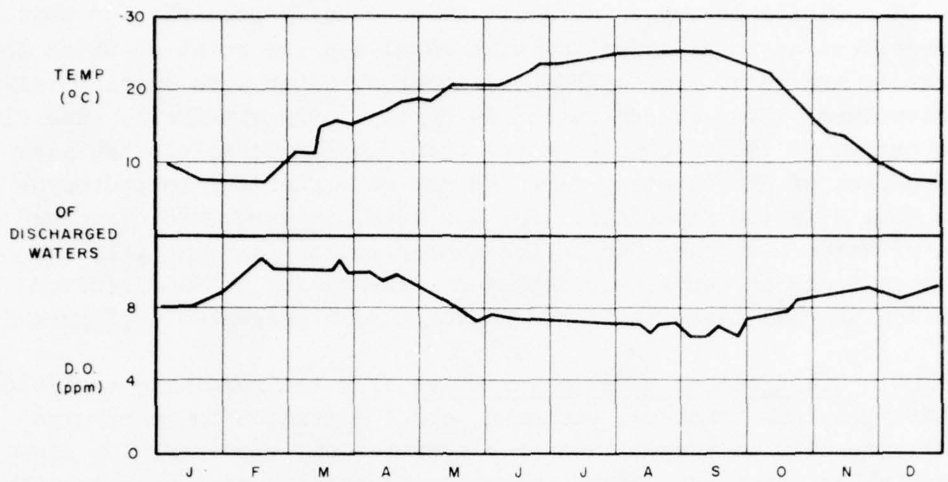
16. The development of temperature stratification in a pool from which water is withdrawn at a lower level presents a slightly different picture. The stratification again begins in late spring with warmer waters in the upper layers and cooler waters in the lower layers. However, as withdrawals are made from the lower level, the cooler winter water is continuously being depleted. Toward late summer or early fall, depending upon the extent of the releases, the volume of water in the hypolimnion may become completely exhausted. The upper layers of warmer water are then drawn down into the discharge area and stratification becomes less distinct. Usually by early winter, the water throughout the entire depth of withdrawal has been mixed and water temperatures are essentially uniform.

17. The effects of stratification on the temperature of the discharged water of a high level and a low level intake are pictured in Figure 2. These data were collected by the Tennessee Valley Authority and summarized by Churchill[1/].

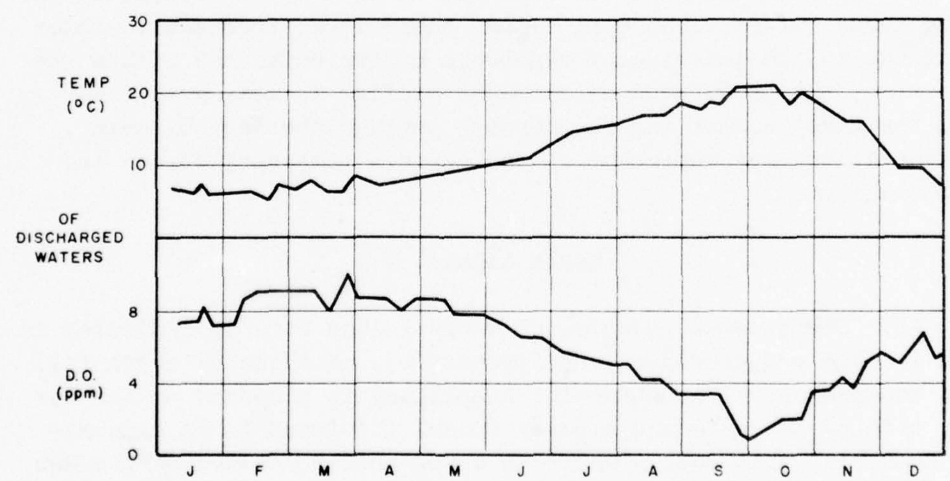
18. Dissolved oxygen stratification The above discussed temperature stratification is the basic underlying cause of the dissolved oxygen stratification observed in reservoirs. The density differences hold water in the lower layers. This in effect hinders atmospheric reaeration of this water while the biochemical oxygen demand, resulting both from dead plankton in the epilimnion settling into the hypolimnion and from bottom deposits continues to exert itself.

1/ This and the following footnotes refer to respectively numbered entries in the Bibliography at the end of the Appendix.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



HIGH LEVEL INTAKE



LOW LEVEL INTAKE

PART C – EFFECTS OF COMPREHENSIVE PLAN

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 2

EFFECTS OF INTAKE LOCATION

19. Dissolved oxygen stratification usually persists for some time dependent upon the amount of withdrawal and the point at which the withdrawals are made. For high-level intakes, water with a relatively high dissolved oxygen concentration is continuously withdrawn. The dissolved oxygen of the discharged water then closely parallels the dissolved oxygen of the incoming flow and may be higher due to photosynthetic action in the reservoir. For low level intakes, the dissolved oxygen of water withdrawn during the summer months is relatively low and may at times be completely depleted. The variation in dissolved oxygen for the two cases mentioned above is also presented in Figure 2.

20. Other stream quality variables For the remaining variables (turbidity, color, hardness, bacteria, etc.) detention in reservoirs generally results in a reduction in concentration. However, for certain variables there may occur temporary increases during construction or for a period of time thereafter. For example, it has been indicated in Part B that an approximate tenfold increase in the turbidity of the downstream waters occurred during the construction of the Neversink Dam. However, the data indicate that this increase has continuously subsided since closure with the reservoir now acting as a huge settling basin. In some cases, after closure of a dam, there is an increase in color content due to the leaching of vegetable matter contained within the pool. Also, the production of hydrogen sulfide is likely to occur during the first summer and may persist through the second summer. These conditions may represent a considerable temporary change in stream quality.

Tocks Island

21. The general location of Tocks Island site is indicated in Figure 1. The proposed dam (see Appendix U), consists of earth fill across the present river channel. A spillway is proposed on the New Jersey side of the site and a power tunnel (if found to be economically feasible) will supply water to a powerhouse located on the New Jersey side slightly downstream from the face of the dam. The pertinent details regarding the Tocks Island Project are presented in Table 1.

22. Temperature structure at Tocks Island With a knowledge of the variation of incoming stream temperature and the application of the above discussion certain general statements can be made concerning the expected temperature stratification. As indicated in Part B, the temperature of the Delaware River at Dingmans Ferry varies from a low of 1°C - 2°C (not including periods of ice cover) during December to early March to a high of about 24°C - 25°C during July and August. With the incoming flow temperatures as given above, and assuming high or mid-level intakes and a relatively constant pool level, a thermocline may be expected to develop which initially would probably be 25-35 feet below the surface and would be about 10-15 feet thick. Toward the end of the summer, the thermocline may be 40-50 feet below the surface and about 15-25 feet thick. Below this thermocline, water temperatures throughout the summer will be approximately 10°C increasing to about 14°C by the end of the summer. With the high level intakes the temperature of the discharged water will closely follow but may be slightly higher than the temperature of the incoming flow.

23. During extreme low flow conditions, the demand imposed on the reservoir for its various intended uses will lower the pool level considerably. As the low flow period persists and if releases are made from a high level at all times the temperature of the discharged water will again be approximately the same or slightly higher than that of the incoming flow. This is due primarily to wind action which will tend to maintain the original thickness of the epilimnion by erosion of the underlying strata.

24. If the dam is equipped for power production, the turbine intakes (which will undoubtedly be located deep in the reservoir) will withdraw water from the hypolimnion. In this event, the water discharged below the dam will have temperatures in the range of 10°C - 14°C during the summer months or until the reservoir is drawn low enough to bring the thermocline or epilimnion down to the intake level.

25. Dissolved oxygen stratification at Tocks Island It has previously been indicated in Part B that the dissolved oxygen concentration of the waters of the Delaware River in the vicinity of the Tocks Island site is relatively good. Over the period of a year, the dissolved oxygen may vary from super-saturation values of 14 ppm to a

low of 7 ppm. Variations within a day may also be very large depending on the extent of algal activity. (See also Part B, Figure 5.) These ranges in dissolved oxygen may be expected in a stream receiving "natural" organic material with only a slight amount of man-made pollution.

26. Using the general concepts indicated in paragraphs 8 and 9 and the variations in dissolved oxygen of the incoming flow, certain observations can be made regarding the dissolved oxygen structure to be expected in the reservoir. In general, with a high level intake the dissolved oxygen concentration of the discharged water will be essentially the same as or slightly higher than that of the incoming flow. Again, as the water level in the pool drops, the epilimnion will be preserved due to the erosion of the lower strata by wind action.

27. Again, if the dam is equipped for power production with turbine intakes deep in the reservoir, the water will be withdrawn from the hypolimnion. During the period of summer stratification, the dissolved oxygen of the water discharged will become progressively lower until late in the summer when the water from the turbines may contain no dissolved oxygen and may pick up only about 1 ppm in the tailrace. It may be 30 to 50 miles downstream before the dissolved oxygen of the river returns to saturation.

28. Other quality characteristics at Tocks Island Part B has indicated that the concentrations of other indicators of stream quality such as hardness, turbidity, color, etc. are not excessive. Because any rapid increase in the concentrations of these constituents may be expected to be "dampened" by the long detention time in this reservoir, the concentrations leaving the pool, during this period will be less than those of the incoming flow. The average concentrations indicated in Part B will remain the same or may possibly be lowered reflecting a water quality suitable for the present uses.

29. However, during the construction of the project and for a short period thereafter, increases may occur in some of these quality characteristics. Notable among these is an expected increase in the turbidity of the waters of the Delaware River in this area. With an

average turbidity of 5 ppm in the Delaware River at Montague, New Jersey, an increase in average turbidity below the dam site to a level of 40-50 ppm may be anticipated during the construction period. The distance that this increase will persist below the dam site is difficult to ascertain. Should a substantial portion of the increase be felt at Easton, Pennsylvania, remedial measures over and above those now practiced may be required by the Easton water treatment plant. However, from the data indicated in Part B, it is not believed that a significant increase will persist beyond Easton. After the construction period, the reservoir will act as a settling basin for the turbidity which fluctuates rapidly during spring and fall runoff periods. Experience with two of the TVA's reservoir systems has indicated a reduction of 61% in average annual turbidities 1/. Summarizing then, a temporary increase in turbidity is expected below the dam site during the period of construction. Following the completion of the project, a reduction in the average annual turbidity will undoubtedly occur.

30. Following the initial filling of the pool, the water discharged may produce tastes and odors not previously experienced depending on the extent of land clearance measures in the reservoir. These tastes and odors may produce some difficulty at downstream water treatment plants. This condition resulting from the decay of organic matter usually persists for two to three summers after closure. Another cause of taste and odor problems may be algal blooms in the reservoir pool. The environmental conditions favorable to algal growth must occur in a definite combination in order to produce blooms of significant size. These conditions involve such factors as temperature, availability of food and sunlight. However, it is not believed that significant growths of algal over and above those now experienced will occur in the Tocks Island pool.

31. During the first summer and possibly during the second summer after impoundment, hydrogen sulfide will probably be produced by decaying vegetation in the hypolimnion. If the turbine intakes are deep in the reservoir, the hydrogen sulfide may be released to the atmosphere in the vicinity of the power house.

32. In conclusion, the quality of the water in the Tocks Island reservoir will be capable of supporting a variety of uses. This is not to infer, however, that treatment will not be required prior to these uses. The Pennsylvania Department of Health has indicated that a minimum of filtration and chlorination will be required for municipal water supplies. It is expected that a similar degree of treatment will be required by New Jersey. From the waste treatment point of view, the criteria established for Zone I, (the basin above Trenton, New Jersey) by the Interstate Commission on the Delaware River require the equivalent of secondary treatment. Both Pennsylvania and New Jersey have indicated officially that this degree of waste treatment will continue to be required as a minimum during the future development of the Delaware River.

Lehigh River Basin Reservoirs

33. The locations of the four projects (Aquashicola, Trexler, Bear Creek and Beltzville) proposed for the Lehigh basin are indicated in Figure 1. A summary of the pertinent design details (abstracted from Appendix U) is presented in Table 1. The Bear Creek reservoir modification was included in the Comprehensive Plan in order to satisfy the projected water supply needs indicated in Appendix P.

34. The discussion of the Tocks Island project relative to the expected water quality in the impoundment generally applies to the above four projects. Since all of the above projects are located in sparsely populated areas and are not on the main stem of the Lehigh River (with the exception of the Bear Creek project), it is expected that the surface water in the impoundments will in general be of excellent quality, although varying degrees of both thermal and dissolved oxygen stratification can be expected to develop in the deeper pools. Due to the geological conditions existing in the Lehigh basin, the hardness concentration is slightly higher than in the main stem of the Delaware. However, because of the high quality of the flow entering the impoundments, it is anticipated that those water uses derived directly from the pool (e.g. recreation) will not be limited by water quality considerations.

Hawk Mountain and Prompton Projects

35. In addition to the above five proposed projects, (Tocks Island and the four projects in the Lehigh basin) two projects are proposed; one at Hawk Mountain on the East Branch of the Delaware River and the other, a revision of the existing Prompton project on the Lackawaxen River. As pointed out in Part B of this Appendix, the waters of the upper portion of the basin are of high quality, and the proposed locations of these sites in this relatively undeveloped area indicates that water quality will not pose a significant problem. Stratification of temperature and dissolved oxygen may be expected, as indicated in detail for the Tocks Island site, but will not assume any major importance due to the relative remoteness of the sites from any large population centers.

Major Schuylkill River Basin Reservoirs

36. Blue Marsh and Maiden sites The location of these two sites is indicated in Figure 1 and the details of the projects are presented in Table 1.

37. In general, the quality of water in both pools should be relatively good and will not limit any water uses. However, samples taken during October, 1949 by the U. S. Geological Survey from Maiden Creek near Temple, Pennsylvania and Tulpehocken Creek above Reading, Pennsylvania indicate relatively high hardness concentrations of about 110 ppm for Maiden Creek and about 170 ppm for Tulpehocken Creek. Although these concentrations are indicative of the geological conditions existing in the Schuylkill basin, the concentration level can be reduced by suitable water treatment methods. The location of these sites, removed from any large population centers existing or anticipated in the foreseeable future, indicates that there will be no particular problem relative to the sanitary quality of the water. Temperature and dissolved oxygen stratification is not anticipated since pool depths will be relatively shallow although it should be recognized that stratification may result from a number of other factors. These may include relation of flow to cross-sectional areas, length of storage periods and exposure to wind action.

Major Control Projects in Delaware

38. The locations of the two sites proposed in the State of Delaware, Newark and Christiana are indicated in Figure 1 and the details are tabulated in Table 1. It is not anticipated that any quality problems will exist in these reservoirs. Severe stratification of dissolved oxygen or temperature is not expected. The water in the reservoirs which are proposed for multi-purpose use should be of high quality.

Limited Development Projects

39. The remaining projects in the Comprehensive Plan under review in this report consist of eight dams and reservoirs as listed below:

(a) Newtown
(b) Paulina
(c) New Hampton
(d) Pequest
(e) Tohickon
(f) French Creek
(g) Evansburg
(h) Hackettstown

40. The general location of these sites is depicted in Figure 1. Table 1 provides a tabular description of the pertinent details for each project. These eight projects are proposed for recreational use only up to about the year 2010 and thereafter for multi-purpose use. It is proposed in Appendix U that the sites for these eight reservoirs be preserved by the respective States for possible future water resources development beyond 2010. In the meantime, however, it is suggested that recreation pools be established at the sites.

41. Conferences held with the State water pollution control agencies indicate that seven of the eight projects will contain water of a high quality. The first project, Newtown may pose a quality problem of a sanitary nature. Treated sewage effluent equivalent to a

population of about 3000 is discharged to Neshaminy Creek from the Doylestown, Lansdale and Warminster Township areas above the proposed location of the project. The discharge of the treated sewage together with the expected increase in the development of the surrounding area may limit the use of this reservoir for recreational purposes. This situation will require additional study by the appropriate State agency prior to construction.

General Conclusions

42. For planning purposes, it is expected that the quality of surface water in the impoundments proposed in Appendix U will be of high quality. This will not, however, preclude the need for the treatment of withdrawals made directly from the pools for municipal and industrial purposes. This essentially is a matter of State policy. It is expected that any degree of water treatment required will consist of a minimum of filtration and chlorination.

43. The treatment of wastes from present and future developments in the areas surrounding the pools will be determined by State policy. Firm policies requiring waste treatment commensurate with the situation already exist in all of the States, and it can be assumed that these policies will continue to apply in the future.

44. At only one site, Newtown (presently proposed for single purpose recreational use,) does there appear to be a water quality problem. The discharge of treated sewage above the site warrants future investigation prior to the initiation of this project.

SECTION IV - EFFECTS OF PROPOSED IMPOUNDMENTS ON DOWNSTREAM WATER QUALITY

General

45. This section evaluates the effects of the proposed impoundments on the quality of water downstream from a particular site or an integrated group of sites. The effects of the nine major control projects in the Delaware Basin above Trenton are considered as well as the effects of the two projects in the Schuylkill River basin. The remaining projects which will not regulate stream flow to any great extent are not considered.

46. The benefits and costs from a water quality point of view which may accrue from proposed impoundments are due to the magnitude and direction of the change in water quality in the reservoir as well as in downstream quality. The change in downstream quality, if any, may result in changes in the needs for waste or water treatment. Also water quality changes may influence the aesthetic value of a watercourse, the habitat of the stream for fish or shellfish or the suitability of the water for recreational purposes or other uses. Except for unusual situations the benefits and costs which may accrue due to these latter uses are difficult to evaluate. Hence primary emphasis in this section is on the changes in waste and water treatment which may result from changes in stream quality. There is an implicit inclusion of the recreational, fishery and aesthetic uses in this section. For example, changes in turbidity, as a result of impoundments may or may not affect water treatment operations and at the same time may increase or decrease the suitability of the stream for fish life. Table 4 lists the qualitative effects of impoundments on quality immediately downstream from the dam depending on the intake location.

47. The discussion below considers the effects of the proposed impoundments on the waters of the Delaware River basin above Trenton, N. J. Following this the effect of flow regulation on the Delaware estuary is considered. Prior to these discussions however, the policies of the basin States regarding the effects of low flow augmentation on the degree of waste treatment is presented.

TABLE 4

Qualitative Effects of Impoundments on Quality of Stream Immediately Below Discharge Point

Quality Characteristic	Effects on Quality Characteristics Resulting From: Low Level Intake	High Level Intake
Dissolved Oxygen	Serious reduction	Small increase due to photosynthesis
Temperature	Marked reduction	Little or no change
Hardness	Some reduction	
Iron and Manganese	Small increase during first or second year of impoundment	Little or no change
Hydrogen Sulfide	Odor for 1-2 years, usually none thereafter	Usually not in discharge
Coliform Bacteria	Some reduction	
Color	Increase for 1-2 years, small decrease thereafter	Small decrease
Turbidity	Large increase during construction, subsequent reduction after impoundment	

State Policies on the Effect of Low Flow Augmentation on the Degree of Waste Treatment

48. New York The State of New York has indicated 3/ that it will accept primary treatment if the flow in the stream (either natural or augmented) is sufficient to maintain the stream standards as classified by the Water Pollution Control Board. In some cases, however, additional treatment may be required if the downstream water uses are of high priority such as drinking water purposes. In essence, then, New York views each stream individually and depending on the stream standards, primary treatment together with the dilution afforded by stream flow may be acceptable. However, since only one major control project, Hawk Mountain, is proposed in the State of New York and since the classification of the Delaware River by the Interstate Commission on the Delaware River in this area already requires secondary treatment, no benefit can be ascribed to increased low flows intended to provide changes in the degree of waste treatment.

49. New Jersey The New Jersey State Department of Health has stated that; "Low flow augmentation is not accepted by the New Jersey State Department of Health as a substitute for presently required degrees of sewage treatment in the Delaware River basin. Low flow augmentation in the Delaware is considered necessary if more stringent requirements as to the degree of sewage treatment are to be avoided or at least deferred for a longer period of time than probably would be effected without augmentation". 3/

50. Pennsylvania The Pennsylvania Department of Health in general accepts the premise that the increase of minimum stream flows can be expected to improve stream quality. However, Pennsylvania points out that in those areas where the population and industrial activity are rapidly expanding, the benefits due to low flow regulation would be offset by the increased waste quantities unless higher degrees of treatment above a primary level are provided. Hence, "the addition of low-flow augmentation would not, in itself, defer the Sanitary Water Board from requiring a degree of treatment higher than exists at the present time."3/ Pennsylvania stated that above Philadelphia, the Sanitary Water Board already requires secondary treatment and it does not appear that the Board will accept a lesser degree solely because of the increase in the minimum stream flow.

51. Delaware The Water Pollution Commission has indicated that it will not require a degree of waste treatment higher than primary.[3] Hence, even if increased fresh water inflow did materially improve the quality of the Delaware estuary it could not be considered as supplanting the secondary degree of waste treatment, since Delaware does not require this higher degree. The policy of the State of Delaware regarding the degree of waste treatment to be provided consists of primary treatment as a minimum.

52. Summary New Jersey and Pennsylvania have indicated that low flow augmentation will not be accepted in lieu of required degrees of treatment. New York considers each stream individually but as pointed out the effect of the Comprehensive Plan in New York sonsists of only one project. Delaware has indicated that it will not require a degree of treatment higher than primary. As will be shown below, these State policies together with the required degrees of treatment and the expected effects of low flow augmentation will not result in any changes in the degree of waste treatment as a result of the Comprehensive Plan. There are other benefits and costs which may result from changes in the quality of the stream, but the effect of these changes on the remaining water uses will of necessity be of a general nature. Changes in both water and sewage plant operation, increased aesthetic and recreational value are extremely difficult to assess monetarily with any degree of accuracy. The remaining paragraphs in this section document as far as possible the changes in stream quality to be expected from increased flow and the effects of these changes on water use.

Effects of Impoundments on Stream Quality of Delaware River Basin Above Trenton, N. J.

53. General As indicated in Part B of this Appendix, the present quality of the waters of the Delaware River basin above Trenton, N. J. is sufficient to support a variety of water uses. It was predicted that by 1980 the expanding population and industrial activity anticipated for this area will increase the pollutional load to approximately that experienced in 1950. This increase however will not adversely affect the present water quality and it is anticipated that all present water uses will continue to exist until

1980. The period after 1980 as indicated in Part B is considerably more nebulous but it is not anticipated that a large scale curtailment of present water uses will occur.

54. The effects on stream quality of the impoundments, proposed for construction by 1980 on quality conditions predicted for this period are discussed below. As indicated in Section II, the major portion of the Comprehensive Plan is proposed for completion by 1981 and following this period three additional structures are proposed in order to satisfy the anticipated water supply needs. Since the prediction of conditions after 1980 is subject to such extreme variations only a general discussion is presented.

55. Although the discussions presented in Section III indicated that stratification problems may exist regarding the quality of water in reservoirs, it is assumed that optimum intake locations will be chosen with respect to water quality and that suitable air entrainment devices will be utilized so as to provide at least the same level of stream quality at the project site as presently exists. The effects than of the proposed impoundments will consist of the relationships between the dilution provided by the augmentation of the minimum flow and the anticipated stream quality.

56. Effects of impoundments on water quality in 1980. Tables 2 and 3 indicate that the Delaware River at Trenton will have a minimun sustained flow of about 4060 cfs including a minimum sustained flow of 518 cfs from the Lehigh River. However, this augmentation will not result in tangible waste treatment benefits prior to 1980. Even without low flow augmentation the minimum 1980 dissolved oxygen level in the Delaware River is not anticipated to drop below an average of about 5 ppm and may not drop below the present average level of 7 ppm. The dissolved oxygen level in the Lehigh River although lower than the Delaware is expected to be acceptable. Since secondary treatment of wastes is already required by Incodel and the States for the Delaware River above Trenton and since it is not anticipated that stream quality problems will develop even without low flow augmentation, no changes or deferrals of the degree of waste treatment are expected to occur as a result of the major control projects of the Comprehensive Plan. Therefore, although there will be

some increase in dissolved oxygen resulting from the augmented flows the increase will not affect the degree of waste treatment. Hence, the benefits will be in the nature of a general area wide "bonus." Since these benefits are somewhat intangible, the calculation of monetary values becomes questionable.

57. Part B indicated the relationship between the flow and hardness content of the Delaware River at Trenton. This pattern is not expected to change significantly before 1980 and hence can be used to qualitatively assess the effects of low flow augmentation. By 1980 the minimum sustained flow at Trenton will be about 4060 cfs. On the basis of Figure 9, Part B, a reduction in average monthly total hardness can be expected to occur. The actual magnitude of the reduction is difficult to estimate accurately but on the basis of Figure 9, Part B a reduction of about 5.0 ppm from the present 85 ppm can be expected. For planning purposes however, only the qualitative effects on hardness are estimated. Reductions in hardness concentration will undoubtedly occur in the Lehigh Basin also and will probably be of the same order of magnitude. While the mean monthly reduction in hardness concentration would be relatively small, some savings in chemical costs will result. No attempt will be made however, to ascribe a monetary benefit to this small reduction in hardness concentration.

58. An increase in iron content, as indicated in Figure 10, Part B, will in part offset the benefit resulting from the decrease in hardness content. This will represent an increase in the water treatment required to remove this excess iron. Again, no attempt is made here to evaluate this cost since the variability in individual water treatment plant practices is so great.

59. Increased turbidity will occur below construction sites and may persist for some distance downstream. While this is in general a transitory effect below a particular dam, the overlapping construction periods of 10-15 years indicated in Table 3 will result in a continuing problem. For instance, during the construction of the Tocks Island project a four-fold increase in turbidity to 40 to 50 ppm may occur immediately below the site and persist as far south as Easton, Pennsylvania resulting in increased water treatment costs

and adverse effects on stream biotas. These temporary costs are not considered to be great enough to warrant consideration in this survey report.

60. Effects of impoundments on water quality in 2010 Since predictions of the pollutional load and resulting water quality to be expected in 2010 are subject to much wider variations, only general statements can be made regarding the effects of the Comprehensive Plan. It is anticipated that the discussion in paragraph 56 ff will apply insofar as the direction of water quality changes is concerned, since there is no reason to believe that the fundamental relationships between flow and iron and hardness will change. Hence, a decrease in hardness and an increase in iron can be expected. As pointed out in Part B, with regard to the dissolved oxygen, the increased pollutional load expected (assuming no "breakthrough" in sewage treatment technology) may reduce dissolved oxygen levels at the critical point of the Delaware to about 5.0 ppm and at times may reduce the dissolved oxygen level below this figure. However, no large scale curtailment of water uses is envisioned during the period ending in 2010. From the waste treatment point of view, it is seen that even without low flow augmentation the stream quality is expected to be within acceptable limits in 2010. Hence, the addition of flow to the natural minimum flow will not produce any changes in the required secondary degree of treatment since there essentially will not be any stream quality problem. With no changes in waste treatment measures anticipated resulting from low flow augmentation, no benefits can be ascribed.

61. Conditions beyond 2010 Although no large tangible stream quality benefits will accrue from the Plan during the period ending in 2010, it is expected that with increasing pollution loads, the beneficial effects of the Plan will become more and more pronounced during the 50 years following 2010. The stream quality of the Delaware above Trenton will then be prevented from potentially deteriorating further by the augmentation of low flows. Quantitative assessments of these benefits however are nebulous and are not made in this report. Qualitatively, the effects of the major control projects on stream quality during the period following 2010 will assume a relatively greater importance and more tangible benefits will result.

62. Summary Table 5 indicates qualitatively the effects on stream quality of the construction of the major control projects, and the subsequent release of impounded water towards increasing the minimum flow of the Delaware River. It is believed that the improvements in certain aspects of the stream quality picture will outweigh any detrimental effects during the life of the Plan and a net benefit will result. It should be recognized however, that at this time the net benefit is of an intangible nature and cannot be economically evaluated with any degree of accuracy.

Effects of Impoundments on Stream Quality of Delaware River Basin from Trenton, N. J. to Delaware Bay

63. General Part B of this Appendix presented an evaluation of the water quality (in terms of dissolved oxygen) of the Delaware estuary for the period 1949-1958 and concluded that (a) the changes in annual average dissolved oxygen from year to year during 1949 - 1959 were due primarily to changes in fresh water inflow (b) the variations in dissolved oxygen over a period of a year, day or tidal cycle can be adequately predicted using statistical techniques, and (c) the results obtained would apply until approximately 1980. The following discussion evaluates the changes in dissolved oxygen within a year due to changes in fresh water inflow and temperature. The regulation of flow by upstream reservoirs, as indicated in Table 3, is then imposed and the resulting effects on dissolved oxygen, are discussed. Quantitative results will be predicted for the period ending in 1980 since, as Part B indicates, the conditions subsequent to this period are subject to considerably greater variation. These are discussed further in paragraph 75.

64. Methodology The sinusoidal relationships for dissolved oxygen and temperature, which were determined in Part B, can be supplemented by an analysis of the variation in fresh water inflow at Trenton across the period of a year. Using the average seasonal dissolved oxygen and temperature curves in conjunction with the developed fresh water flow curve, simultaneous plotting of the variables can be made to determine their interrelationships. However, the curve developed to describe the variation in fresh water inflow at Trenton must be modified to account for the time of travel between the head of tide and the point in the estuary which is under consideration.

TABLE 5

QUALITATIVE EFFECTS OF LOW FLOW AUGMENTATION ON STREAM QUALITY OF DELAWARE RIVER ABOVE TRENTON, NEW JERSEY

Quality Characteristic	Ending	Relative effects on quality existing during period
Dissolved Oxygen	1980	Small increase
	2010	Smaller increase
Hardness	1980	Small decrease
	2010	Smaller decrease
Iron	1980	Small increase
	2010	Smaller increase
Turbidity	1980	Large "temporary" increase below each site
	2010	Large "temporary" increase below each site

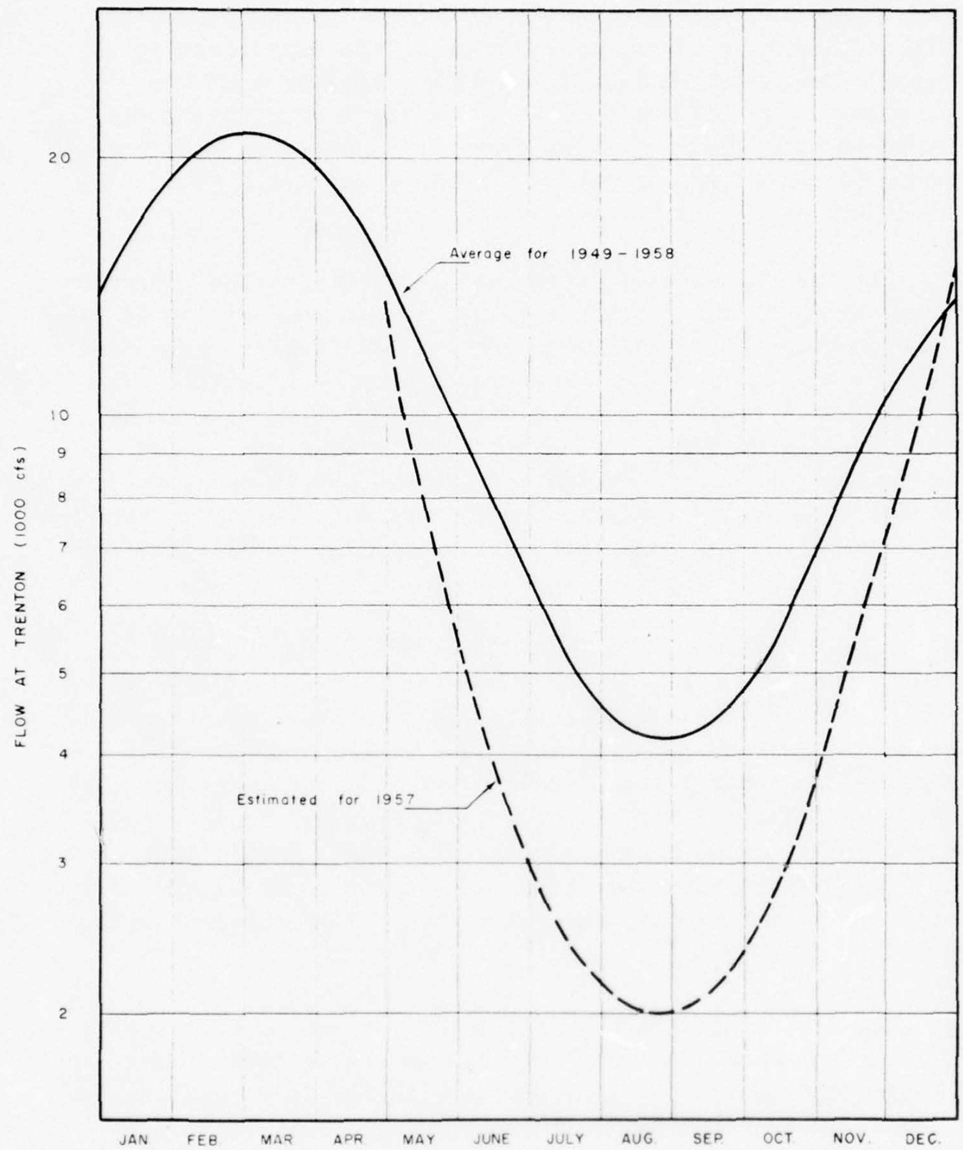
These times of travel can be estimated from the instantaneous dye tests conducted with the Delaware River model at Vicksburg, Mississippi.[6] The application of the travel time to the flow curve at Trenton results in an "effective" fresh water flow curve at the particular point in the estuary. This curve together with the dissolved oxygen and temperature curves previously developed then provides a means of estimating the effects of flow regulation on dissolved oxygen.

65. The analysis presented in Part B represents the variation in dissolved oxygen or temperature for the average year during 1949-1958. Therefore, conversion of these results to low flow years can be obtained by calculating a new predicted mean and variation. This conversion can be determined from the difference between the annual mean for the average year and the annual mean for the particular year under consideration. An estimate can therefore be obtained of the variations in dissolved oxygen, temperature and flow for a year such as 1957 and the effects of imposed flow regulation can then be evaluated.

66. Results Figure 3 indicates the results of the analysis performed on the mean monthly flows at Trenton from August 1949 to July 1958, the period for which dissolved oxygen data were available. The logarithm of the flow was used to obtain a more accurate "fit." The correlation coefficient ($r = 0.52$ with $N = 108$) indicates the significance (less than 1%) of the equation. Figure 3 further indicates the estimated change in the average flow curve during the low flow year of 1957 for the months of May to December. This curve was visually fitted since time and fund limitations did not permit an extensive analysis.

67. Figure 4 indicates the relationships used to estimate the time of mass travel from Trenton to various points in the estuary based on instantaneous dye tests conducted with the Delaware River model.[6] The effects of increasing flow at Trenton will be felt by wave travel at different points in the estuary somewhat earlier than indicated in Figure 4. However, these wave travel times are not as descriptive as the mass travel time when quality conditions are being evaluated since maximum dilution and movement is due to the effect of

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART C — EFFECTS OF COMPREHENSIVE PLAN

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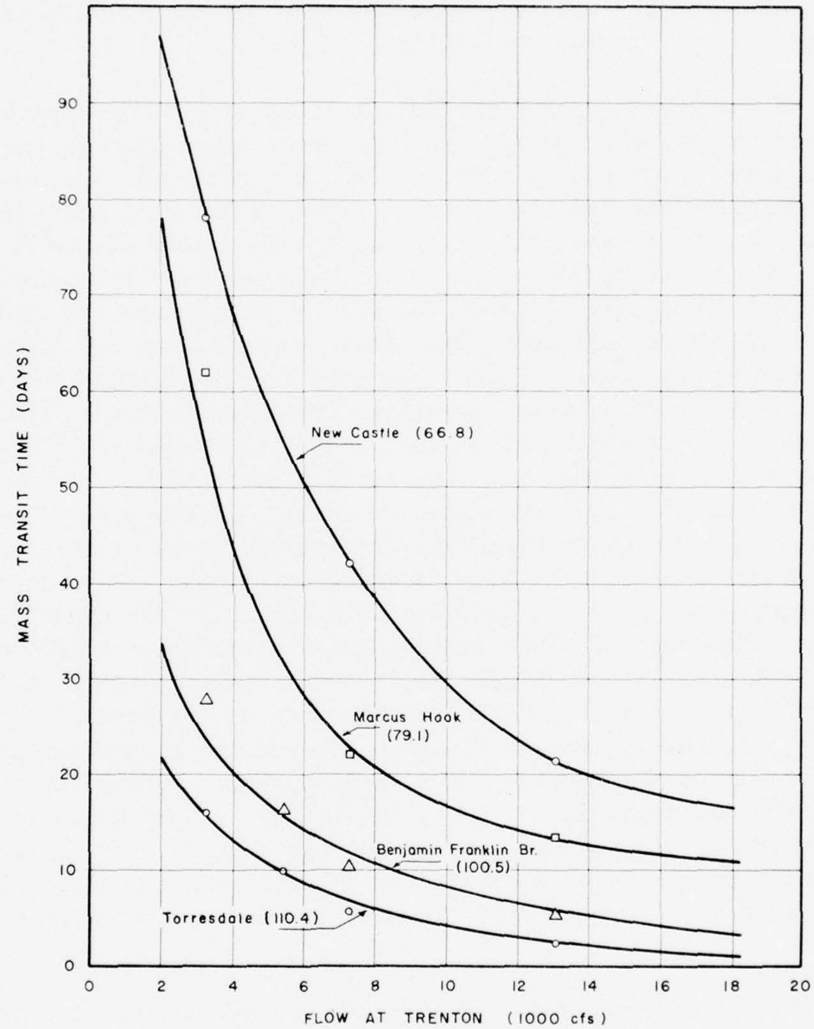
FIGURE 3

FRESH WATER FLOW VARIATIONS

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART C — EFFECTS OF COMPREHENSIVE PLAN

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 4

MASS TRANSIT TIMES TO VARIOUS POINTS IN THE DELAWARE ESTUARY

the mass at any given point. The travel times in Figure 4 thus represent the best estimates of when the flow at Trenton will significantly affect the dissolved oxygen in the estuary.* The asymptotic nature of the travel times of the lower flows at the further downstream points in the estuary indicates that the application of these times is subject to wide variation.

68. Figures 5 and 6 present the results at four stations for dissolved oxygen as a function of both fresh water flow at the station and temperature during the average year for 1949-1958. If the average sinusoidal flow variation at Trenton given in Figure 3 had been used, the relationship between dissolved oxygen and flow would be eliptical in shape where the length of the minor axis is given by the extent of the phase differences. This can be seen by inspecting the dissolved oxygen-temperature relationships. These correlations result in different slopes and smaller minor axes than those indicated for the dissolved oxygen and flow relationships. The slope indicates maximum temperatures occur almost at minimum dissolved oxygen and the smaller minor axis indicates that the time differences between maximum temperature and minimum dissolved oxygen is small. If the time of maximum temperatures and minimum dissolved oxygen were equal, the relationship reduces to a straight line, sloping negatively. A positive slope of the straight line would indicate both variables are exactly in phase and the negative slope indicates the variables are 180° out of phase. For a 90° phase difference, the relationship would still be eliptical with the axes parallel to the axes of the variables. When the times of travel given in Figure 4 are applied to the variation of flow at Trenton, the sine curve is distorted. During the higher flow months and depending on the point in the estuary which is being analyzed the distortion is less than during the low flow months. The distorted flow curve for a particular point alters the basic geometry between pure sine waves thereby leading to the relationships as shown in Figure 5.

69. It is seen from Figures 5 and 6 that as the flow decreases at Torresdale and the temperature increases, the dissolved oxygen decreases to a minimum of 4 ppm during the early part of August following

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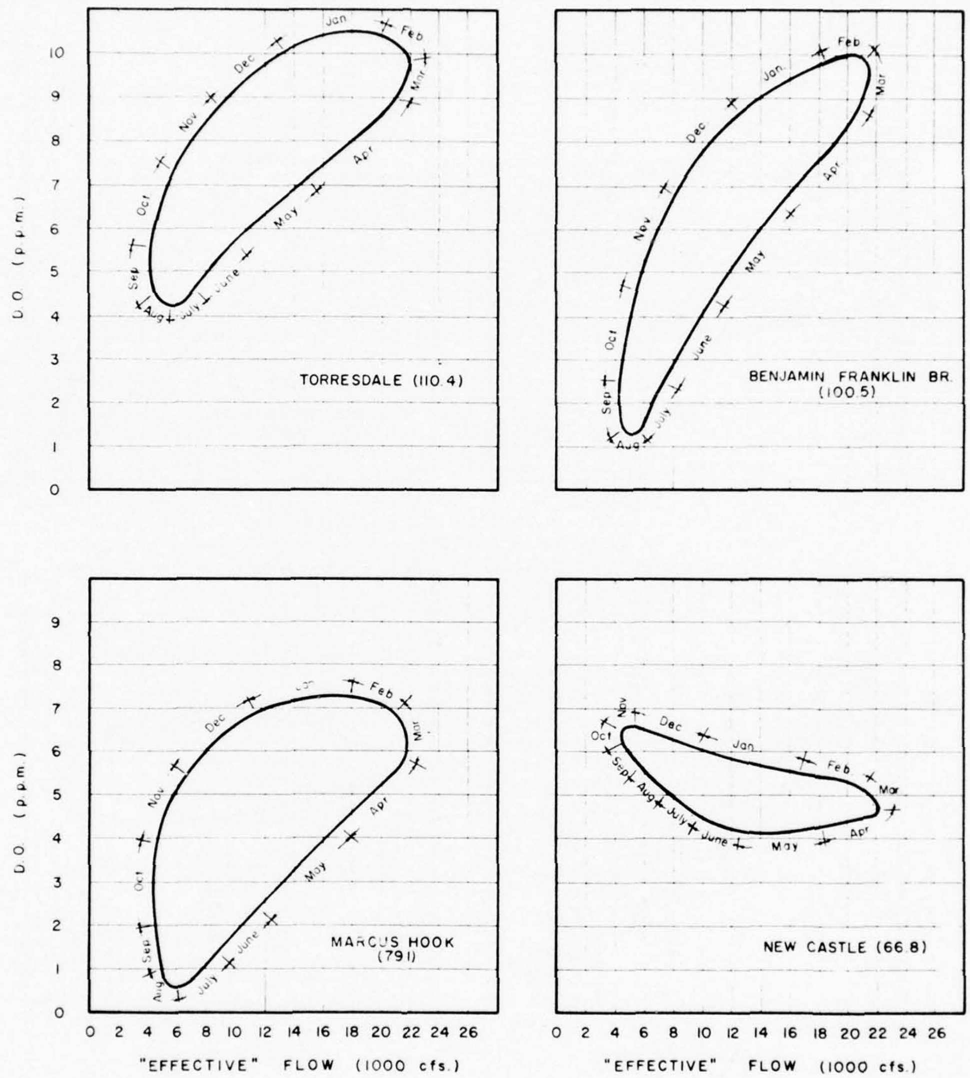
* Since the preparation of this Appendix, additional data has been collected which alters Figure 4 slightly, but has no effect on subsequent results and conclusions.



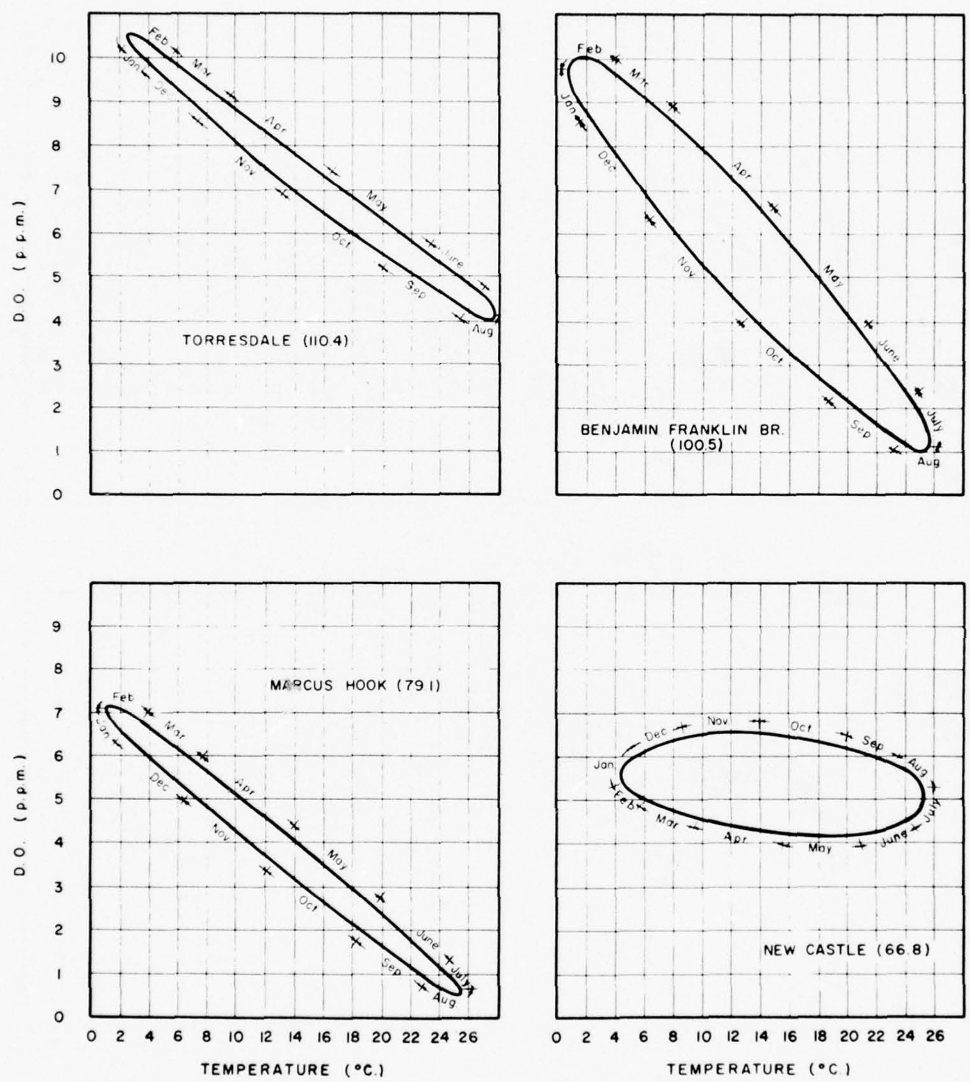
PART C — EFFECTS OF COMPREHENSIVE PLAN

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 5

DISSOLVED OXYGEN — FLOW RELATIONSHIPS AVERAGE YEAR (1949-1958)

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART C — EFFECTS OF COMPREHENSIVE PLAN

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 6

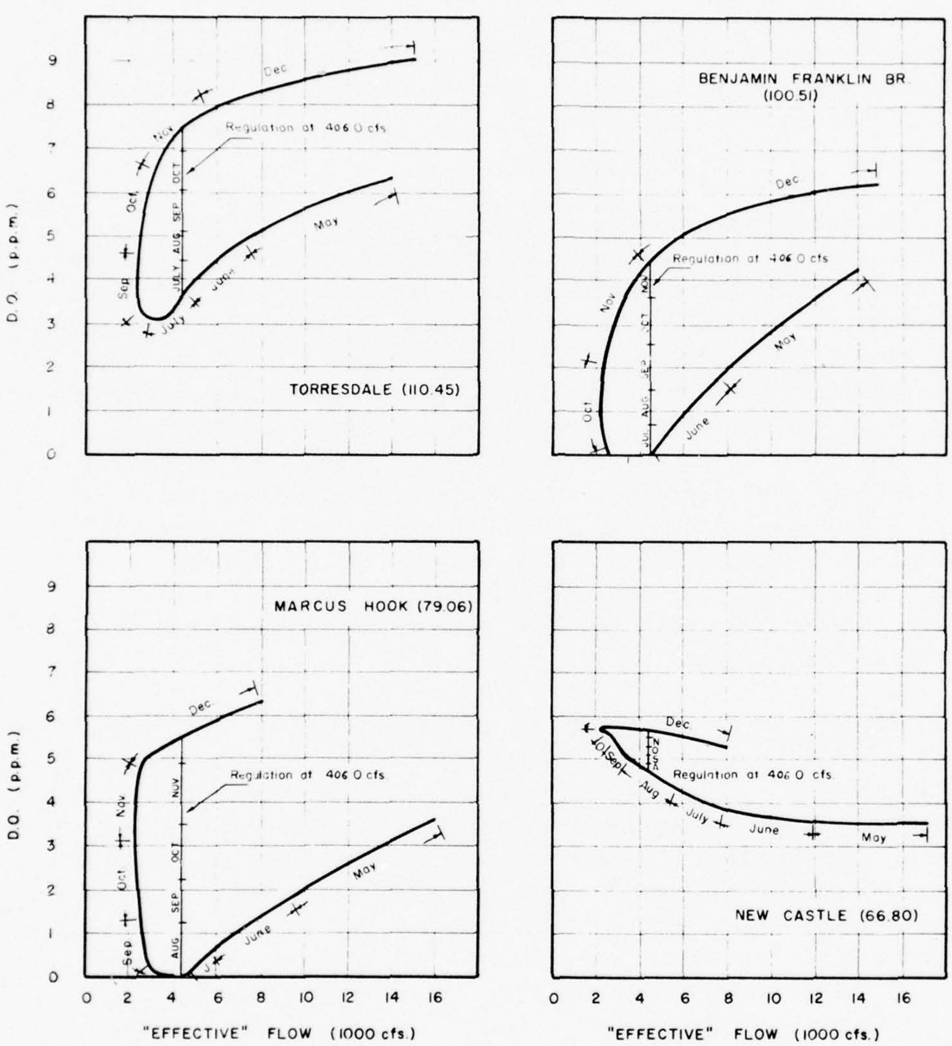
DISSOLVED OXYGEN — TEMPERATURE RELATIONSHIPS AVERAGE YEAR (1949-1958)

which, during small changes in flow, the dissolved oxygen increases due to the decrease in temperature. At New Castle, Delaware, however, the relationships are quite different due principally to the changes in travel time. It is seen that the low point of dissolved oxygen occurs during May after which, with decreasing fresh water flow, the dissolved oxygen increases even with the increasing temperature. This indicates the effect of incoming Delaware Bay water during the low fresh water flow months.

70. Figure 7 presents the estimated relationships for four stations during 1957. The same considerations mentioned in the above paragraph apply. The only changes in the relationships occur in the levels of dissolved oxygen and flow, and times of occurrence of flow. Also as pointed out in Part B, the dissolved oxygen at various times of the tide or day may be considerably higher or lower than indicated in Figure 7. The extent of the changes and the estimated times of occurrences are given in Tables 15 (Part B) and A2-4. For example, Figure 7 indicates that for Marcus Hook at the end of June, the average daily dissolved oxygen is about 0.6 ppm. Table 15 (Part B) shows a change of $\pm$ 1.4 ppm due to tidal and daily influences. Therefore, depending on the time of tide and day, the dissolved oxygen at the end of June may vary from 0.0 ppm to 2.0 ppm with an expected average of 0.6 ppm.

71. Effects of flow regulation The imposition of a constant flow during particular times of the year affects the relationships indicated in Figures 6 and 7 in a unique way. Since these curves must of necessity remain continuous functions, the flow regulation effect can be estimated by use of a constant relationship during flow augmentation. For example, at Torresdale during 1957 (Figure 7) the flow dropped to approximately 4060 cfs during July. If, as is planned for 1980 conditions, the flow were regulated at 4060 cfs, the continuous nature of the dissolved oxygen - flow relationship can only be preserved by a straight line from the middle of July to about the middle of November. The time scale is then compressed into this line with the dissolved oxygen increasing linearly during the period of regulation. Hence, it is estimated that for Torresdale, a regulated flow of 4060 cfs during 1957 would have resulted in a dissolved oxygen level during July from 3.6 ppm to 4.4 ppm as contrasted with a previous range during July of 3.6 ppm to 3.2 ppm.

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



PART C — EFFECTS OF COMPREHENSIVE PLAN

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 7

DISSOLVED OXYGEN — FLOW RELATIONSHIPS

1957

72. Table 6 presents in tabular form the estimated changes in dissolved oxygen resulting from a regulated flow of 4060 cfs during a low flow year similar to 1957. It should be emphasized that the values given in Table 6 are estimates of daily averages which would be obtained if samples were taken on a continuous basis. Considerable variation around this average may occur depending on the time of tide or day. For example, at New Castle a range of ± 1.6 ppm dissolved oxygen may occur during certain times of the tide or day. Hence, the dissolved oxygen at the beginning of August could range from 2.8 ppm to 6.0 ppm with an estimated average of 4.4 ppm which is the value shown in Table 6. The same procedure applies to all stations shown in Figure 7 and Table 6. For the actual values of the variation around the average, see Table 15, Part B. An increase in dissolved oxygen will occur throughout the estuary except at the New Castle, Delaware station where a decrease will occur. This decrease can be attributed in part to the increased travel time resulting from the constant flow of 4060 cfs which transports upstream water to this station at a more rapid rate than that previous to flow regulation. Therefore, the stabilization of organic matter which previously occurred at the upstream stations now occurs further downstream. The organic matter from the upstream station did not have sufficient time for its complete stabilization. The completion of this stabilization then occurs at the downstream station with a subsequent reduction in dissolved oxygen over that experienced previously.

73. Inspection of Figure 5, indicates that during a year similar to the average year for 1949 - 1958 the dissolved oxygen will not be affected. The relationships indicated in Figure 7 are representive of a low flow year with a frequency of occurrence of about 20% for the minimum average 30 day flow. The increase in average daily dissolved oxygen during years with flow regimes intermediate between those of 1957 and the average year for 1949 - 1958 will probably be less. Hence, as the increment between the regulated flow of 4060 cfs and the minimum flow for any given year becomes smaller, the effect of a regulated flow of 4060 cfs on the dissolved oxygen will be less pronounced until the minimum flow exceeds 4060 cfs at which time no effect on dissolved oxygen will be noted.

TABLE 6

EFFECT OF REGULATED FLOW OF 4060 cfs
ON DISSOLVED OXYGEN*

	Range of Average Daily Dissolved Oxygen (ppm)	
Torresdale	Before Regulation	After Regulation
July	3.6 - 3.2	3.6 - 4.4
Aug.	3.2 - 3.5	4.4 - 5.1
Sept.	3.5 - 4.6	5.1 - 6.1
Oct.	4.6 - 6.4	6.1 - 6.9
Nov.	6.4 - 8.0	6.9 - 8.0
Benj. Franklin Bridge		
July	0.0 - 0.0	0.0 - 0.4
Aug.	0.0 - 0.0	0.4 - 1.4
Sept.	0.0 - 0.2	1.4 - 2.4
Oct.	0.2 - 2.1	2.4 - 3.4
Nov.	2.1 - 4.4	3.4 - 4.4
Dec.	4.4 - 6.4	4.4 - 6.4
Marcus Hook		
Aug.	0.0 - 0.4	0.0 - 1.2
Sept.	0.4 - 1.4	1.2 - 2.2
Oct.	1.4 - 3.2	2.2 - 3.5
Nov.	3.2 - 4.8	3.5 - 4.9
Dec.	4.8 - 6.2	4.9 - 6.2
New Castle		
Aug.	4.4 - 5.0	4.4 - 4.9
Sept.	5.0 - 5.5	4.7 - 5.1
Oct.	5.5 - 5.7	5.1 - 5.3
Nov.	5.7 - 5.7	5.3 - 5.5
Dec.	5.7 - 5.3	5.5 - 5.3

*Estimated effects during future years with quality and flow conditions similar to those prevailing in 1957.

Note: The values given in this Table are estimated daily averages. Considerable variation around these figures can occur depending on the time of tide or day. For actual variation values, see Table 15, Part B.

74. Although it is estimated that for the Delaware River above the Delaware State line an increase in dissolved oxygen will occur as a result of the regulated flow, this increase is relatively small averaging about 1-1.5 ppm. As indicated, the regulated flow will produce a decrease in dissolved oxygen of about 0.3-0.4 ppm in Delaware. These values as always are subject to experimental variation although it is believed that the order of magnitude is correct. However, the benefits as well as the detrimental effects of these changes are mainly intangible under the 4060 cfs flow regulation. In other words, the increase in dissolved oxygen above the State line is not sufficient to warrant any changes or deferrals in the degrees of waste treatment required by the States and Incodel. Further, it is obvious that as far as the State of Delaware is concerned, no deferral or change in required waste treatment measures (e.g. the substitution of low flow regulation for secondary treatment) could possibly be made. Indeed, as was indicated previously, Delaware does not at this time intend to require a degree of treatment higher than primary, but may well be forced to do so if additional upstream pollution is transported downstream. However, the decrease in quality which will be experienced by Delaware resulting from a regulated flow of 4060 cfs is not believed to be great enough to warrant such action at this time. Summarizing then, the changes in the quality of the estuary are not considered to be sufficient to result in any tangible benefits or costs. Rather, it is believed that for the entire estuary a net intangible benefit will occur where the increase in quality above the State line would outweigh the decrease in quality below the State line.

75. Conditions in 2010 Part B indicated that the total pollution load to the estuary in 2010 would be between 900,000 #BOD/day and 1,400,000 #BOD/day. These estimates and the resulting level of stream quality are subject to considerable variation depending on many factors as pointed out in Part B. Because of this, the estimation of quantitative concentrations of dissolved oxygen which may result from a regulated flow of 4,720 cfs at Trenton in 2010 would be of little value. However, some general statements can be made.

76. It was indicated above that an increase in fresh water flow to the estuary from the present minimum monthly of 2,610 cfs to a regulated minimum of 4,060 cfs in 1980 will result in a relatively small increase in dissolved oxygen above the State line and an even smaller decrease in dissolved oxygen below the State line. Although it is anticipated that the quality of the estuary in 2010 will be somewhat less than at present, it is believed that the further increase in regulated flow from 4060 to 4720 will not result in a further significant increase in dissolved oxygen. Nor it is believed that the additional increase in fresh water inflow will significantly decrease further the dissolved oxygen levels below the State line. Further, it is not anticipated, then that the increase in fresh water flow augmentation will change the dissolved oxygen levels in the estuary to such an extent that additional sewage treatment facilities can be deferred. As was pointed out in Part B, the quality of the estuary can be maintained at least at present levels only by substantial increases in waste treatment measures. Undoubtedly, the addition of low flow regulation will supplement the waste treatment programs, but it is estimated that the quality of the estuary will not be altered materially by the augmentation of low flows. A tangible monetary benefit can not therefore be ascribed to the increase in flow, although an intangible supplemental benefit should be recognized.

77. <u>Conditions beyond 2010</u> Assuming no large scale breakthrough in present methods of waste treatment, it is estimated that the pollutional load to the estuary subsequent to 2010 will continue to increase. Low flow augmentation may then assume a more important role in the maintenance of quality of the estuary. The installation of even higher degrees of treatment may then possibly be forestalled for a period of time. However, it should be recognized again that conditions below the State line may deteriorate even further which may result in the need for increased treatment in Delaware as a result of the augmentation of low flows. Whether the balance between these two factors will be favorable or unfavorable is extremely difficult to determine at this time. This determination should be made at the appropriate time in the future so that the long range effects of the Comprehensive Plan can be evaluated more precisely.

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BIBLIOGRAPHY

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GLOSSARY

GLOSSARY

The following definitions are included in order to assist in a better understanding of the terminology used in this report.

Algae. - Primitive aquatic plants which utilize their food by the process of photosynthesis.

Alkalinity. - The capacity of a water for neutralizing acid due to the presence of carbonate, bicarbonate and hydroxide ions.

Biochemical Oxygen Demand. - The quantity of oxygen utilized in the biochemical oxidation of organic matter in a specified time and at a specified temperature; a measure of the amount of oxidizable material present.

Chlorides. - Chemical compounds of the element chlorine with another element or combination of elements; sodium chloride, calcium chloride and magnesium chloride occur most frequently. In water, these compounds contribute to the total salinity.

Coliform Bacteria. - A group of organisms indicating possible fecal pollution and the potential presence of disease producing bacteria. Normally expressed as the most probable number (MPN) of organisms per 100 ml.

Correlation Coefficient. - A measure of the amount of variation in observed data explained by an assumed mathematical relationship; hence a measure of the validity of the assumed relationship.

Hardness. - A characteristic of water due chiefly to the existence of the carbonates and sulfates of calcium and magnesium.

Odor Threshold. - The point at which after successive dilutions with odorless water, the odor of the water sample can just be detected. Expressed quantitatively by the number of times the sample is diluted with the odorless water.

Glossary (Cont.)

Oxygen. - Dissolved - Oxygen dissolved in sewage, water or other liquid expressed in parts per million or percent saturation.

Sag Curve - The profile of dissolved oxygen content along the course of a stream resulting from deoxygenation associated with biochemical oxidation of organic matter and reaeration through the absorption of atmospheric oxygen and through biological photosynthesis.

Saturation - The maximum quantity of dissolved oxygen that a liquid exposed to the atmosphere can contain at a given temperature and pressure.

Supersaturation - A condition in water whereby dissolved oxygen contents are greater than can physically be dissolved by exposure of the water to the atmosphere. Usually caused in streams by the photosynthetic action of algae.

Phenol. - A colorless or pinkish crystalline substance C_6H_5OH produced by the distillation of many organic substances, such as wood, coal, tar, etc. When dissolved, it is commonly called carbolic acid.

Photosynthesis. - The formation of complex organic compounds and oxygen from simple inorganic compounds under the stimulus of light and the presence of chlorophyll.

Reaeration. - The absorption of oxygen by a liquid, the dissolved oxygen content of which has been depleted.

Population Equivalent. - (1) The calculated population which would normally contribute the same amount of BOD per day; a common base is 0.167 pounds of 5-day BOD per capita per day. (2) For industrial wastes, the estimated number of people

Glossary (Cont.)

required to contribute sewage equal in strength to the industrial waste.

Statistical Significance. - The percent change or "odds" that a calculated result of the test of an hypothesis is due to chance alone. Five percent or 10% levels are commonly used. For 5%, the odds are equal to or less than 5 out of 100 that the result is due to chance alone.

Treatment. - Primary - Usually screening and sedimentation of sewage which removes a high percentage of suspended matter but little colloidal or dissolved matter.

Secondary - After primary treatment, the treatment of sewage by biological methods to remove colloidal and dissolved matter.

Turbidity. - A suspension of fine visible material which prevents the passage of light through the liquid.

ATTACHMENT 1

INVENTORY OF MUNICIPAL WATER SUPPLY
AND WASTE DISPOSAL FACILITIES

ATTACHMENT 1

INVENTORY OF MUNICIPAL WATER SUPPLY
AND WASTE DISPOSAL FACILITIES

1. General This inventory obtained through the cooperation of the appropriate agencies of the States of New York, New Jersey, Pennsylvania and Delaware and the Interstate Commission on the Delaware River shows both the water and waste facilities for individual communities or groups of communities. The purpose of the inventory is to provide a concise presentation of the use and subsequent disposal of the waters of the Delaware River basin in order to assist in more accurately assessing future needs and changes necessary to maintain maximum utilization of potential water resources.

2. Industrial water use and waste disposal facilities are not listed since the collection of individual industrial data was predicated on the commitment that the data would not be released on an individual basis.

3. The inventory accounts for approximately 90% of the population of the Delaware River basin served by community type water and waste facilities. Municipalities with connected populations with less than 5000 were not listed nor were communities which withdraw water from ground water sources and thence dispose of their waste water to ground. More detailed data on the water and waste facilities of all communities are available in the regularly published inventories of the Public Health Service. The work reported on in the three parts of this Appendix did however include all municipal and industrial facilities of water supply and waste disposal.

4. It will be noted that each entry is listed under a particular water course from which it either draws water or into which it discharges wastes. Some communities are listed more than once depending on their source of supply or point of discharge to the stream. The controlling element then is the particular stream. Under each stream heading are listed the communities as well as the entering tributaries on which other communities may be located.

5. Detailed notes on columns:

(a) Under the first column are listed either a community, tributary, or private company which services communities or authorities formed by a group of communities for purposes of water supply or waste disposal. Under each stream heading, the entries are listed in accordance with distance from the mouth of the stream.

(b) Source, River Mile - For the stream heading, the distance in miles from the mouth of the stream at which point the entry (except for tributaries) withdraws water. (See paragraph 6).

(c) Treatment - The principal water treatment features are identified according to the code listed below. In general, the symbols are arranged in the order in which treatment occurs.

A - Aeration
C - Chemical dosage for coagulation or softening
D - Disinfection
F - Filters
K - Chemical dosage for corrosion control or water stabilization
M - Mixing device or tank
N - Ammoniation
R - Recarbonation
S - Sedimentation
T - Chemical taste and odor control
V - Fluoride adjustment.

(d) Population served, 1955 - The estimated 1955 population in thousands served by the water facilities of the entry listed.

(e) Use (mgd), 1955 - The estimated 1955 average daily use in million gallons per day provided to the distribution system by the water facilities of the entry listed.

(f) Population served, 1958 - See note (d).

(g) Use (mgd) 1958 - See note (c).

(h) Population served, 1958 - The estimated 1958 population in thousands served by the waste disposal facilities of the entry listed.

(i) Flow (mgd), 1958 - The estimated 1958 average daily flow discharged to the water course by the waste outlet or treatment facilities of the entry listed.

(j) Treatment - The principal waste treatment facilities are identified according to the code listed below. In general, the symbols are arranged in the order of sewage flow, with sludge treatment symbols following thereafter.

A - Aeration
B - Sludge beds
C - Settling tanks
D - Digester, separate sludge
E - Chlorination
F - Filters
G - Grit chambers-
H - Sludge storage tanks (not second stage digestion units)
I - Sewage application to land
K - Chemical treatment
L - Lagoons
O - Grease removal or skimming tanks - not incidental to settlings tanks
S - Screens
T - Sludge thickener
V - Mechanical sludge dewatering
Z - Sludge conditioning

(k) Population equivalent - The estimated pollution load discharged in terms of an equivalent amount of people in thousands. Computed on the basis of 0.17 pounds of biochemical oxygen demand per person per day. (See Glossary for definition).

(l) Discharge, River Mile - For the stream heading, the distance in miles from the mouth of the stream at which point the entry discharges waste water. See paragraph 6.

6. River mile designation All river miles along the Delaware River are referred to the mouth of Delaware Bay as 0.0. River miles for tributaries are referred to the confluence with the main stream or other tributary as 0.0.

MUNICIPAL WATER SUPPLY
AND WASTE DISPOSAL FACILITIES

Name	WATER SUPPLY						WASTE DISPOSAL				
			1955		1958		1958				
	River Mile	Treatment	P. S. (1000)	Use (mgd)	P. S. (1000)	Use (mgd)	P. S. (1000)	Flow (mgd)	Treatment	Pop. Equiv. (1000)	River Mile
	DELAWARE BAY (D-0.0)										
Cape May, N. J.	Grnd	D	7.3	1.4	7.3	1.4	5.3	0.4	None	5.3	0.0
Mispillion River (D-11.2)											
Maurice River (D-19.4)											
St. Jones River (D-23.7)											
Cohansey River (D-38.3)											
	DELAWARE RIVER (D-48.2)										
Salem River (D-52.6)											
Christina River (D-70.7)											
Wilmington and New Castle County, Del.	a/						130.0 b/	39.8	GCDZ	350.0	71.2
Artesian Water Co., Del.	Grnd c/	None	25.0 d/	2.6	--	--					
Newark, Del.	Grnd e/	None	5.0	0.6	--	--			f/		
Penns Grove, N. J.	Grnd	DKT	16.0	0.8	16.5	0.9	6.7	0.4	SECDEB	5.7	72.7
Stoney Creek (D-74.2)											
Naamen Creek (D-78.6)											
Chester, Pa.	g/						70.0 h/	11.0	SCB	70.0	80.0
Chester Creek (D-82.9)											
Ridley Creek (D-84.0)											
Central Delaware County Sewer Authority							80.0 i/	8.0	GSACDB	12.0	84.9
Crum Creek (D-84.9)											
Darby Creek (D-85.2)											
Mantua Creek (D-89.5)											
Woodbury Creek (D-91.6)											
Philadelphia, Pa. j/											
Southwest Sewage Treat. Plant							870.0	74.5	SGKCHDL	325.0	92.0
Schuylkill River (D-92.0)											

DELAWARE RIVER (D-48.2) (Cont.)

Big Timber Creek (D-95.4)											
Philadelphia, Pa. k/											
Southeast Sewage Treat. Plant							677.5	58.2	GSACH	262.0	96.7
Newton Creek (D-96.9)											
Camden, N. J.	Grnd	D	92.7	22.0	98.0	22.4	116.5 l/	18.0	SGCAFCV	356.0	98.1
m/	Grnd	D	33.1	3.3	33.1	3.3					
Baldwins Run (D-100.0)											
Cooper River (D-100.9)											
Philadelphia, Pa. n/											
Northeast Sewage Treat Plant							669.0	122.4	SGCACDL	610.0	104.0
Pennsauken Creek (D-105.4)											
Palmyra Boro., N. J.	Grnd	AKD	12.1	0.7	13.4	0.9	5.9	0.3	SCFDB	2.5	107.3
Pennypack Creek (D-109.8)											
Philadelphia, Pa. o/											
Torresdale Plant	110.4	CMSFFDV	1050.0	179.5	--	--					

a/ See Christina River (D-70.7), Brandywine Creek (C-1.5), White Clay Creek (C-10.0), Stoney Creek (D-74.2), Naamen Creek (D-78.6).
b/ Serves Wilmington and 33 other communities in New Castle County.
c/ See also Christina River (D-70.7), Delaware Water Co.
d/ Serves 16 of above 33 communities served by Wilmington and New Castle County waste treat. plant. Also serves 59 other communities not served by sewerage systems.
e/ See also Christina River (D-70.7), Delaware Water Co.
f/ At Wilmington-New Castle Plant
g/ Diverted 13.0 mgd in 1955 from Octororo Creek-Susquehanna basin. Serves 100,000 population in Chester, Marcus Hook and surrounding area.
h/ Includes Chester and portions of surrounding area.
i/ Serves all or part of 6 communities in Delaware County.
j/ For water supply, see Delaware-110.0, Schuylkill-9.3, 11.8, 14.7.
k/ See note under Southwest Sewage Treat. Plant.
l/ See also Baldwins Run Plant, D-100.0.
m/ Also served by New Jersey Water Co., Stockton Plant.
n/ See note under Southwest Sewage Treat. Plant.
o/ For waste treatment, see Delaware River - 92.0, 96.7, 104.0

Name	WATER SUPPLY River Mile	Treatment	1955 P. S. (1000)	1955 Use (mgd)	1958 P. S. (1000)	1958 Use (mgd)	WASTE DISPOSAL 1958 P. S. (1000)	1958 Flow (mgd)	Treatment	Pop. Equiv. (1000)	River Mile
	DELAWARE RIVER (D-48.2) (Cont.)										
Rancocas Creek (D-111.2)											
Neshaminy Creek (D-115.6)											
Burlington, N. J.	Grnd[a]	NDCSFDT	15.0	1.9	15.0	1.9	12.3	2.8	SGCDFECB	10.2	117.8
Bristol, Pa.	118.5[b]	DCTSMFDNK	29.1[c]	5.5	30.0	6.0	18.0	1.8	SCFLECD	1.8	119.2
Levittown, Pa.	122.5	CDMFDKV	40.1	2.9	56.0	3.6	56.0[d]	4.5	SCADEB	3.5	122.2
Florence, N. J.	Grnd	AD	7.0	0.9	7.2	0.9	5.2	0.4	SCFEDB	3.5	123.1
Bordentown, N. J.	Grnd	D	8.2	0.9	9.0	0.9	5.4	0.5	SCFCEB	2.9	128.3
Crosswicks Creek (D-128.4)											
Trenton, N. J.	e/						141.8	21.1	SGCBL f/	234.0	131.8
Morrisville, N. J.	g/						10.0	1.3	SCFDBE	1.5	133.0
Assunpink Creek (D-133.7)											
Morrisville, N. J.	134.3	CATSMFDT	10.0	0.9	10.5	1.2			h/		
Trenton, N. J.	135.5	NDTCSFDK	155.2[i]	26.0	157.5	26.5			j/		
Delaware-Raritan Canal k/											
Tohickon Creek (D-157.0)											
Pohatcong Creek (D-177.4)											
Phillipsburg, N. J.	Grnd[l]	D	24.1	3.8	24.8	3.8	18.3	1.8	SGCAZVDE	0.5	183.0
Easton, Pa.	m/						45.0	5.0	SGCFCEDDB	1.7	183.1
Lehigh River (D-183.3)											
Bushkill Creek (D-183.8)											
Easton, Pa.	184.5	SCMSFDV	50.0	4.7	50.0	4.7			n/		
Martins Creek (D-190.6)											
Paulins Kill (D-207.0)											
Brodhead Creek (D-213.0)											
Neversink River (D-254.5)											
Sparrow Bush Cr. (D-257.0)											

DELAWARE RIVER (D-48.2) (Cont.)

Mongaup River (D-261.0)
Lackawaxen River (D-277.7)
East Br. Del. R. (D-330.7)

a/ Some additional supply from Delaware River.
b/ Also ground.
c/ Ground only.
d/ Serves part of Bristol Township.
e/ See Delaware River - 135.5.
f/ Secondary plant under construction 1958.
g/ See Delaware River - 134.3.
h/ See Delaware River - 133.0.
i/ Serves estimated 24,000 in Hamilton Township (Crosswicks Creek - 3.4) and 15,000 in Ewing-Lawrence Townships (Assunpink Creek - 10.0).
j/ See Delaware - 131.8.
k/ Diversion of 15 mgd (1957) from Delaware basin waters to Raritan River for water supply for Elizabethtown and New Brunswick Water Companies and several industrial water users.
l/ 0.5 mgd from reservoirs.
m/ See Delaware River - 184.5.
n/ See Delaware River - 183.1.

			WATER SUPPLY				WASTE DISPOSAL				
			1955		1958		1958				
Name	River Mile	Treatment	P. S. (1000)	Use (mgd)	P. S. (1000)	Use (mgd)	P. S. (1000)	Flow (mgd)	Treatment	Pop. Equiv. (1000)	River Mile
			MISPILLION RIVER (D-11.2)								
Milford, Del.	Grnd	None	5.0	0.5	5.1	0.5	5.2	0.4	SCEDB	3.5	12.7
			MAURICE RIVER (D-19.4)								
Millville, N. J.	Grnd	ACD	16.0 a/	1.0	18.0 a/	1.2	16.8	2.0	SGCFCEDB	5.2	18.0
	b/	FMS		2.7		2.3					
Vineland, N. J.	Grnd	None	15.0	2.2	20.0	2.5	8.0	0.8	CI	5.6	24.0
			ST. JONES RIVER (D-23.7)								
Dover, Del.	Grnd	None	6.0	1.1	6.0	1.2	5.5	0.9	SCEDB	3.9	16.5
			COHANSEY RIVER (D-38.3)								
Bridgeton, N. J.	Grnd	CKM	19.2	3.4	21.0	3.4	25.0	2.8	SGCFCEB	4.3	8.0
			SALEM RIVER (D-52.6)								
Salem, N. J.	Grnd	ACDFKMS c/	9.5 c/	0.7	9.5 c/	0.7	9.2	1.2	CEDB	5.8	1.0
	d/			0.7		0.7					
			CHRISTINA RIVER (D-70.7)								
Brandywine Creek (C-1.5)											
White Clay Creek (C-10.0)											
Delaware Water Co.	13.3 e/	SFD	f/	3.6 g/	--	--					
			BRANDYWINE CREEK (C-1.5)								
Wilmington, Del.	2.2	SFD	148.9	25.0	--	--			h/		
East Br. Brandywine Cr. (B-19.0)											
West Br. Brandywine Cr. (B-27.4)											
			EAST BRANCH BRANDYWINE CREEK (B-19.0)								
Downington, Pa.	i/	SFD	5.0	0.6	5.8	0.7	6.0	0.6	SCFDBEC	1.2	6.0

				WEST BRANCH BRANDYWINE CREEK (B-27.4)							
Coatesville, Pa.	j/	SFD	16.0	2.0	18.0	2.1	16.0	1.6	SCGACEDB	3.2	3.0
			WHITE CLAY CREEK (C-10.0)								
Delaware Water Co. k/	2.2	SFD	--	3.3	--	--					
			STONEY CREEK (D-74.2)								
Wilmington Suburban Water Corp., Del. l/	0.6	SFD	7.0	0.3	--	--					
			NAAMEN CREEK (D-78.6								
Wilmington Suburban Water Corp., Del. m/	3.8	SFD	2.0	0.2	--	--					
			CHESTER CREEK (D-82.9)								
West Chester Boro., Pa.	13.2	SFDCM	18.0	2.0	18.0	2.1	8.0	0.8	SGCFFCEDB	--	n/
							8.0	0.8	SGCFEDB	1.8	o/
			RIDLEY CREEK (D-84.0)								
Media Boro., Pa.	8.0	DCMCFDKT	20.0	1.5	25.0	1.9	6.0	0.6	SCFCFDB	0.8	6.5

a/ Total
b/ Also draws from Union Lake
c/ Total
d/ Also draws from Elkington Pond, Lurral Lake
e/ See also White Clay Creek (C-10.0)
f/ Serves Newark, Wilmington Suburban Water Co., New Castle County Water Co., Artesian Water Co.
g/ 2/3 to industry
h/ See Delaware River - 71.2
i/ From Coplan Run and Beaver Creek
j/ From Rock Run
k/ See also Christina River - 13.3
l/ Serves 40 communities, total pop. - 30,000. See also Naamen Creek (D-78.6) and Delaware Water Co.-Christina River (D-70.7)
m/ See Note: Wil. Sub. Co. on Stoney Creek
n/ To Goose Creek
o/ To Taylor Run

Name	River Mile	Water Supply: Treatment	Water Supply 1955: P. S. (1000)	Water Supply 1955: Use (mgd)	Water Supply 1958: P. S. (1000)	Water Supply 1958: Use (mgd)	Waste Disposal 1958: P. S. (1000)	Waste Disposal 1958: Flow (mgd)	Waste Disposal: Treatment	Pop. Equiv. (1000)	River Mile
CRUM CREEK (D-84.9)											
Philadelphia Suburban Water Co. a/, Plant #1	11.0	CTSMSFNKD	200.0	15.0	--	--	b/				
DARBY CREEK (D-85.2)											
Muckinapattus Creek (Da-2.5)											
Darby Creek Sewer Authority							70.0	7.0	GSACFDVZ	10.5	5.0
MUCKINAPATTUS CREEK (Da-2.5)											
Muckinapattus Sewer Authority							26.5	2.6	SGACFDB	3.9	0.1
MANTUA CREEK (D-89.5)											
Paulsboro, N. J.	Grnd	ACDFKM	8.5	1.2	10.0	--	7.8	0.7	CEDB	9.4	2.5
Chestnut Branch (M-9.1)											
CHESTNUT BRANCH (M-9.1)											
Pitman Boro., N. J.	Grnd	DA	7.0	0.4	--	--	5.1	0.5 d/	SCADEB c/ CFCB c/	1.8 d/	4.5
Glassboro, N. J.	Grnd	D	5.9	0.8	7.0	1.0	6.0	0.6	CFCEB	0.3	7.0
WOODBURY CREEK (D-91.6)											
Woodbury, N. J.	Grnd	AND	14.0	1.4	14.5	1.7	3.5 e/ 7.5 f/	0.2 1.4	SCEB SCE	2.7 6.9	3.0 3.0
SCHUYLKILL RIVER (D-92.0)											
Philadelphia, Pa. g/											
Belmont Plant	9.3	CMSFFDV	350.0	60.7	--	--					
Wissahickon Creek (S-10.7)											
Philadelphia, Pa. h/											
Queen Lane Plant	11.8	CMSFFDV	600.0	103.4	--	--					
Roxborough Plant	14.7	CMSFDV	140.0	24.5	--	--					

Conshohocken Boro., Pa.			i/				10.8	1.1	SCEFDZV	1.5	20.8
Bridgeport Boro., Pa.			j/				5.5	0.6	SCEB	3.2	24.8
Norristown Boro., Pa.	26.8	ACTSFDK	55.0 k/	5.3	60.0	6.0	51.0	5.5	SGCACDEB	6.0	24.8
Perkiomen Creek (S-32.8)											
Pickering Creek (S-35.1)											
Phoenixville, Pa.	39.1	CDTSMFDNK	16.6	2.5	18.0	2.6	13.0	1.9	SCACEDB	1.8	37.1
Royersford Boro., Pa.			l/				4.0	0.4	SCFCEB	0.4	43.4
Spring City Boro., Pa.			m/				3.5	0.4	SGFCEDB	0.4	43.4
Home Water Co., Pa.	44.4	CDCTSFD	7.5	1.0	--	--					
Pottstown Boro., Pa.	56.2	CMSFD	30.0	4.1	32.0	4.2	24.5	2.6	SGCACEDB	3.6	54.2
Antietam Creek (S-66.6)											
Wyomissing Creek (S-76.3)											
Reading, Pa.	n/	ASCNMTC FFKD	130.0	16.9	130.0	16.9	110.0	12.0	SCFCDEB	20.0	77.5
Maiden Creek (S-86.1)											
Little Schuylkill R. (S-102.5)											

a/ Serves 28 political subdivisions in northern half of Del. County. See also Perkiomen Creek, Pickering Creek, Pennypack Creek

b/ Communities in this area served by Central Delaware County Sewer Authority, Darby Creek S. A., Muckinapattus S. A.

c/ Two plants - part to Chestnut Branch, part to Mantua Creek

d/ Total

e/ Plant #1

f/ Plant #2

g/ For waste treatment, see Del. R. - 92.0, 96.7, 104.0

h/ See note above

i/ Served by Phil. Sub. Water Co.

j/ Served by Norristown Water Co.

k/ Serves Bridgeport and 5 other communities

l/ Served by Home Water Co.

m/ Served by Home Water Co.

n/ See Antietam Creek (S-66.6), Maiden Creek (S-86.1)

Name	River Mile	Treatment	WATER SUPPLY 1955 P. S. (1000)	WATER SUPPLY 1955 Use (mgd)	WATER SUPPLY 1958 P. S. (1000)	WATER SUPPLY 1958 Use (mgd)	WASTE DISPOSAL 1958 P. S. (1000)	WASTE DISPOSAL 1958 Flow (mgd)	WASTE DISPOSAL Treatment	Pop. Equiv. (1000)	River Mile
SCHUYLKILL RIVER (D-92.0) (Cont.)											
Schuylkill Haven Boro., Pa.	a/						4.5	4.5	SSCDEB	3.0	116.0
West Br. Schuylkill River (S-115.7)											
Tumbling Run (S-118.2)											
Pottsville, Pa.	b/						24.5	2.5	None	35.0	120.4
Mill Creek (S-120.6)											
Silver Creek (S-124.1)											
WISSAHICKON CREEK (S-10.7)											
Sandy Run (W-10.1)											
Ambler Boro., Pa.	Grnd	D	14.0	1.0	15.0	1.3	4.5	0.8	SCACEDDB	0.7	12.0
SANDY RUN (W-10.1)											
Abington Twp., Pa.			c/				20.0	1.5	SCACEDVZ	1.5	2.0
PERKIOMEN CREEK (S-32.8)											
Phila. Suburban Water Co.	21.2	d/	92.0	7.0	--	--					
Skippack Creek (P-2.7)											
North Br. Perkiomen Creek (P-10.7)											
SKIPPACK CREEK (P-2.7)											
Souderton Boro., Pa.	Grnd	D	4.7	0.2	5.0	0.3	4.2	0.3	SGCFEB	0.6	12.0
NORTH BR. PERKIOMEN CREEK (P-10.7)											
Perkasie Boro., Pa.	Grnd	D	4.5	0.2	5.1	0.3	5.2	0.3	SCFCEB	0.5	17.0
PICKERING CREEK (S-35.1)											
Phila. Suburban Water Co. Plant #4	0.2	CTSFNKD	66.0	5.0	--	--					

AD-A043 793 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 8/6

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)

DEC 60

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4 OF 6

AD A043793

				ANTIETAM CREEK (S-66.6)								
Mt. Penn Boro., Pa.		Grnd	ND	9.3	0.5	10.9	0.7	3.6	0.4	SCACEDB	0.6	4.0
Reading, Pa.	e/	6.1										
				WYOMISSING CREEK (S-76.3)								
Wyomissing Valley Sewer Authority				f/				13.5	1.6	SKCFCETDVX	2.5	1.5
Shillington, Pa.		Grnd	CSFND	7.0	0.3	8.0	0.4	5.0	0.4	g/	5.0	3.1
Mohnton Boro., Pa.				h/				2.0	0.2	i/	2.0	4.8
				MAIDEN CREEK (S-86.1)								
Reading, Pa.	j/	2.8										
				LITTLE SCHUYLKILL RIVERS (S-102.5)								
Owl Creek (LS-20.2)												
Panther Creek (LS-21.2)												
Tamaqua Boro., Pa.		k/						10.0	1.0	None	10.0	21.4
						OWL CREEK (LS-20.2)						
Tamaqua Boro., Pa.		0.5	ADT	13.0	1.0	13.0	1.0	l/				

a/ See Tumbling Run (S-118.2)
b/ See Wolf Creek, (Mill Creek-3.9)
c/ Served by Phil. Sub. Water Co.
d/ Treated at Pickering Creek plant
e/ See Reading, Schuylkill-77.5
f/ Communities served by Reading, Pa.
g/ To future Mohnton Plant
h/ Served by Shillington
i/ Plant under construction 1958
j/ See Reading, Schuylkill-77.5
k/ See Owl Creek (LS-20.2)
l/ See Little Schuylkill R.-21.4

Name	River Mile	Treatment	WATER SUPPLY 1955 P. S. (1000)	WATER SUPPLY 1955 Use (mgd)	WATER SUPPLY 1958 P. S. (1000)	WATER SUPPLY 1958 Use (mgd)	WASTE DISPOSAL 1958 P. S. (1000)	WASTE DISPOSAL 1958 Flow (mgd)	Treatment	Pop. Equiv. (1000)	River Mile
PANTHER CREEK (LS-21.2)											
Lansford-Coaldale Municipal Authority	a/	D	13.0	0.7	13.0	0.7	b/				
Panther Valley Combined Sewer Commission							16.5 c/	1.7	None	16.5	5.0
Summit Hill, Pa.	Grnd	DN	4.5	0.2	4.5	0.2	d/				
WEST BR. SCHUYLKILL RIVER (S-115.7)											
Minersville Boro., Pa. Dyers Run (WBS-10.5)	e/						4.0	0.4	None	4.0	7.5
DYERS RUN (WBS-10.5)											
Minersville Boro., Pa.	0.2	DCN	8.6	0.8	8.6	0.9					
TUMBLING RUN (S-118.2)											
Schuylkill Haven Boro.,Pa.	0.5	D	10.0	0.9	10.0	0.9	f/				
MILL CREEK (S-120.6)											
St. Clair Boro., Pa. Wolf Creek (M-3.9)			g/				3.0	0.3	None	3.0	2.0
WOLF CREEK (M-3.9)											
Pottsville, Pa.	0.5 h/	D	46.0	6.0	44.0	7.0	i/				
SILVER CREEK (S-124.1)											
Blythe Twp., Pa.	2.7	D	20.0 j/	1.8	20.0	1.8	k/				
BIG TIMBER CREEK (D-95.4)											
Little Timber Creek (BTC-0.2)											
Westville, N. J.	Grnd	DKKM	4.7	0.3	7.5 l/	0.5	5.5	0.6	CDB	4.7	0.6

			BIG TIMBER CREEK (D-95.4) (Cont.)								
Beaver Brook (BTC-3.4)											
Depthford Twp., N. J.		m/					5.4	0.5	CACEDB	0.5	7.0
			LITTLE TIMBER CREEK (BTC-0.2)								
Gloucester, N. J.	Grnd	ADFS	14.2	2.4	16.0	2.5	15.6	2.3	SGCFVD	3.8	0.3
Mt. Ephraim Boro., N.J.	Grnd	n/	4.8	0.2	5.0	0.2	4.5	0.5	SCFECDB	5.6	2.4
			BEAVER BROOK (BTC-3.4)								
Runnemeade Boro., N. J.	Grnd	o/	6.0	0.3	6.7	0.4	4.2	0.2	SCACDB	0.7	1.5
			NEWTON CREEK (D-96.9)								
South Br. Newton Cr. (N-0.9)											
Peters Creek (N-2.0)											
Collingswood Boro, N. J.	Grnd	ADFS	25.9	1.9	25.9	2.2	18.0	2.0	SGCACEDBV	12.6	3.5
Haddon Heights Boro., N.J.	Grnd	p/	7.3	0.3	7.3	0.3	6.2	0.6	SGCAFEDB	4.9	q/

a/ From Still Creek, Bear Creek, Broad Run
b/ See Panther Valley Combined Sewer Commission
c/ Serves Lansford, Coaldale, Summit Hill
d/ See Panther Valley Combined Sewer Commission
e/ See Dyers Run (WBS-10.5)
f/ See Schuylkill River - 116.0
g/ Served by Pottsville
h/ Also Indian Run, Eisenhuth Res. and 2 other streams
i/ See Schuylkill River - 120.4
j/ Serves portions of 18 communities in Blythe Twp.
k/ Majority of communities served discharge to ground
l/ Serves part of Depthford Twp.
m/ Served by several water companies with water purchased from Woodbury and Gloucester municipal supplies
n/ Purchased from New Jersey Water Co.
o/ Served by New Jersey Water Co.
p/ Served by New Jersey Water Co.
q/ To Kings Run

Name	River Mile	Treatment	WATER SUPPLY 1955 P. S. (1000)	1955 Use (mgd)	1958 P. S. (1000)	1958 Use (mgd)	WASTE DISPOSAL 1958 P. S. (1000)	1958 Flow (mgd)	Treatment	Pop. Equiv. (1000)	River Mile
SOUTH BR. NEWTON CREEK (N-0.9)											
Audubon Boro., N. J.	Grnd	a/	9.5	0.5	9.5	0.5	10.0	1.0	CFCEDB	2.8	2.4
PETERS CREEK (N-2.0)											
Oaklyn Boro., N. J.	Grnd	b/	4.6	0.2	4.6	0.2	4.9	1.4	SCFCEB	1.6	0.5
BALDWINS RUN (D-100.0)											
Camden, N. J.		c/					3.5	2.0	SGCADB	4.5	0.5
COOPER RIVER (D-100.9)											
Pennsauken Twp., N. J.	Grnd	AFKS	35.0 d/	2.5	35.0d/	2.8	27.0 d/	2.7	SGCEFDB	6.1	4.6
Haddonfield Boro., N. J.	Grnd	AF	10.5	1.0	13.0	1.1	11.1	1.5	SCFDEB	6.7	8.0
PENNSAUKEN CREEK (D-105.4)											
So. Br. Pennsauken Cr. (P-3.4)											
No. Br. Pennsauken Cr. (P-3.4)											
SOUTH BR. PENNSAUKEN CREEK (P-3.4)											
Maple Shade Twp., N. J.	Grnd	ACDFKST	9.5	0.6	11.0	0.8	5.8	0.7	CFECB	1.6	3.3
NORTH BR. PENNSAUKEN CREEK (P-3.4)											
Moorestown Twp., N. J.	Grnd	ACSFK	8.0	0.9	11.0	1.0	8.8	1.1	CFECDB	2.5	4.0
PENNYPACK CREEK (D-109.8)											
Phila. Sub. Water Co. Plant #2	11.0	CTMSFKD	13.0	1.0	13.0	1.0					
Upper Moreland Twp., Pa.	Grnd	D	12.0	0.3	15.0	0.7	12.0	1.0	SCACEDBB	1.0	14.0

			RANCOCAS CREEK (D-111.2)								
Riverside, N. J.	Grnd e/	D	7.2	0.4	8.0	0.5	8.0	0.9	SGCFFCEDB	15.0	0.9
North Br.Rancocas Cr.(R-7.8)											
			NORTH BR. RANCOCAS CREEK (R-7.8)								
Mount Holly Twp., N. J.	Grnd	ASFND	11.5	0.9	16.8	1.0	7.8	1.0	SGCFCEDV	4.8	4.0
			NESHAMINY CREEK (D-115.6)								
Fairless Hills, Pa.	Grnd	ID	6.3	0.5	7.6	1.0	15.0	1.0	SGCDACEB	1.5	5.1
Mill Creek (N-9.1)											
Cooks Run (N-30.0)											
West Br. Neshaminy Co.(N-31.6)											
			MILL CREEK (N-9.1)								
Phila. Sub. Water Co. Plant #3	2.0	CTMSFNKD	145.0	11.0	145.0	11.0					
			COOKS RUN (N-30.0)								
Doylestown Boro., Pa.	Grnd	D	5.3	0.4	5.3	0.5	6.8	0.7	SCFFEB	0.7	2.6
			WEST BR. NESHAMINY CREEK (N-31.6)								
Lansdale Boro., Pa.	Grnd	D	11.0	1.3	11.0	1.3	10.5	1.0	SGCFECBD	0.8	4.5
			CROSSWICKS CREEK (D-128.4)								
Hamilton Twp., Pa.		f/					29.0	3.3	SGCFEDB	7.6	3.4
			ASSUNPINK CREEK (D-133.7)								
Shabakunk Creek (A-4.0)											

a/ Served by New Jersey Water Co.
b/ See foot note above a/
c/ See Delaware River - 98.1
d/ Also serves Merchantville
e/ Served by Delaware Water Co.
f/ See Trenton, Delaware - 135.5

Name	River Mile	Treatment	WATER SUPPLY 1955 P. S. (1000)	WATER SUPPLY 1955 Use (mgd)	WATER SUPPLY 1958 P. S. (1000)	WATER SUPPLY 1958 Use (mgd)	WASTE DISPOSAL 1958 P. S. (1000)	WASTE DISPOSAL 1958 Flow (mgd)	Treatment	Pop. Equiv. (1000)	River Mile
SHABAKUNK CREEK (A-4.0)											
Ewing-Lawrence Sewerage Authority		a/					16.8	3.1	SSFCDB	4.0	6.0
TOHICKON CREEK (D-157.0)											
Quakertown Boro., Pa.	Grnd	D	5.5	0.5	6.1	0.6	5.0	0.5	SCFCEDB	0.6	18.0
POHATCONG CREEK (D-177.4)											
Shabbecong Creek (P-17.0)											
SHABBECONG CREEK (P-17.0)											
Washington Boro., N. J.	Grnd	ND	4.6	0.6	6.0	0.8	5.2	0.4	SKCFCEDB	0.4	0.2
LEHIGH RIVER (D-183.3)											
Bethlehem, Pa.	b/						79.0	8.0	SCFDEB	16.0	10.0
Allentown, Pa.	Grnd c/	CSFD	107.0	20.3	107.0	20.3	95.0	17.3	SCFCEB	18.0	13.0
Catasauqua Boro., Pa.	Grnd	D	4.7	0.8	4.8	0.8	7.7 d/	0.8	SCF	0.8	15.0
Hockendaugua Cr. (L-18.0)											
Northampton, Pa.	19.0	CDKMRSTH	28.0	1.5	32.8	1.8			e/		
Aquashicola Creek (L-32.0)											
Pohopoco Cr. (L-35.6)											
Lehighton Boro., Pa.	f/						6.6	0.6	SSCEDB	0.4	37.0
HOCKENDAUGUA CREEK (L-18.0)											
Northampton, Pa.	g/						9.5	1.0	SCFCEDB	0.8	1.0
AQUASHICOLA CREEK (L-32.0)											
Palmerton Boro., Pa.	Grnd	D	7.4	0.3	7.0	0.5	5.8	0.6	SCFB	0.1	1.0
POHOPOCO CREEK (L-35.6)											
Wild Creek (P-9.5)											

					WILD CREEK (P-9.5)							
Bethlehem, Pa.	6.0	DCSKFND	90.0	20.0	90.0	20.0	h/					
			LONG RUN (L-39.9)									
Lehighton Boro., Pa.	2.0i/	D	7.5	0.7	8.0	0.8				j/		
		BUSHKILL CREEK (D-183.8)										
Shoeneck Creek (B-5)												
			SHOENECK CREEK (B-5)									
Nazareth, Pa.	Grndk/	D	16.0l/	2.1	17.8	2.2	5.8	0.5	SCFCEB	0.4	6.0
		MARTINS CREEK (D-190.6)										
Bangor, Pa.	m/		10.0	1.2	10.1	1.1	n/					
		PAULINS KILL (D-207.0)										
Newton Town, N. J.	o/	D	5.8	0.7	6.7	0.8	6.3	0.5	SCFCEB	1.5	21.0

a/ See Trenton, Delaware - 135.5.
b/ See Pohopoco Creek (L-35.6)
c/ Approx. 1/4 of supply from Little Lehigh River.
d/ Takes sewage from North Catasauqua.
e/ See Hockendaugua Creek (L-18.0).
f/ See Long Run (L-39.9).
g/ See Lehigh River - 19.0.
h/ See Lehigh River - 10.0.
i/ Also from Pine Run
j/ See Lehigh River - 37.0.
k/ Also three small creeks.
l/ Serves 6 other unsewered communities in area.
m/ From north fork Martins Creek and 8 springs.
n/ No public sewer system.
o/ From Morris Lake and Pine Swamp Brook.

Name	River Mile	Treatment	WATER SUPPLY 1955 P. S. (1000)	1955 Use (mgd)	1958 P. S. (1000)	1958 Use (mgd)	WASTE DISPOSAL 1958 P. S. (1000)	1958 Flow (mgd)	Treatment	Pop. Equiv. (1000)	River Mile
			BRODHEAD CREEK (D-213.0)								
McMichaels Creek (B-3.0)											
Sambo Creek (B-4.0)											
			McMICHAELS CREEK (B-3.0)								
Stroudsberg, Pa.	Grnd	D	7.0	1.0	7.0	1.0	6.5	1.0	SCFECD	0.9	0.2
			SAMBO CREEK (B-4.0)								
East Stroudsberg, Pa.	1.0	ND	8.0	2.0	--	--	1.0	0.1	None	1.0	0.6
			NEVERSINK RIVER (D-254.5)								
Port Jervis, N. Y.	a/						9.8	1.0	GCFE	0.1	1.0
Sheldrake Stream (N-27.6)											
South Fallsburgh, N. Y.	Grnd	None	10.0 b/	0.8	--	--	10.0 b/	0.8	SCFCEB	4.0	29.5
New York, N. Y.	34.0 c/			116.7 d/	--	79.4 d/					
			SHELDRAKE STREAM (N-27.6)								
Kiamesha Creek (S-2.0)											
Loch Sheldrake Br.(S-6.0)											
			KIAMESHA CREEK (S-2.0)								
Monticello, N. Y.	3.5	CDFKMSTV	10.0 b/	0.7	15.0 b/	0.7	14.0 b/	0.6	GSCFFB	2.5	e/
Kiamesha, N. Y.	Grnd	D	5.0 b/	0.5	8.0 b/	0.7	7.5 b/	0.6	SCFEV	0.8	3.5
			LOCH SHELDRAKE BROOK (S-6.0)								
Loch Sheldrake, N. Y.	f/						5.5 b/	0.3	SCFCFEB	0.5	2.2

			SPARROW BUSH CREEK (D-257.0)								
Port Jervis, N. Y.	4.8	NDTK	9.5	0.9	10.0	1.1			g/		
			MONGAUP RIVER (D-261.0)								
Liberty, N. Y.	h/	ND	12.0b/	1.8	14.5b/	1.9	12.0b/	1.5	SCFCFEDB	1.0	29.7
			LACKAWAXEN RIVER (D-277.7)								
Honesdale, Pa.	i/	KD	7.0	0.6	7.0	1.0	5.6	0.6	None	7.0	24.0
			EAST BR. DELAWARE RIVER (D-330.7)								
New York, N. Y.	30.0j/		--	234.3k/	--	188.5k/					

a/ See Sparrow Bush Creek (D-257.0).
b/ Summer population and flows.
c/ Neversink Reservoir.
d/ Diverted from basin to New York City.
e/ To Cold Spring Brook.
f/ No public supply.
g/ See Neversink River (D-254.5).
h/ From Lily Pond and Revonah Reservoir.
i/ From Glass and Cajaw Ponds.
j/ Pepacton Reservoir.
k/ Diverted from basin to New York City.

ATTACHMENT 2

TECHNICAL DISCUSSION ON THE ANALYSIS

OF

STREAM QUALITY VARIABLES IN TIDAL ESTUARIES

Attachment 2

TECHNICAL DISCUSSION ON THE ANALYSIS OF STREAM QUALITY VARIABLES IN TIDAL ESTUARIES

Basic Assumption

1. The general equation for a curve with a sinusoidal variation is utilized. For a simple one-cycle variation, this equation is of the form:

$$Y = Y_m + Y_a \frac{\sin t - t_o}{p}$$

where the terms are those depicted in Figure A2 -1

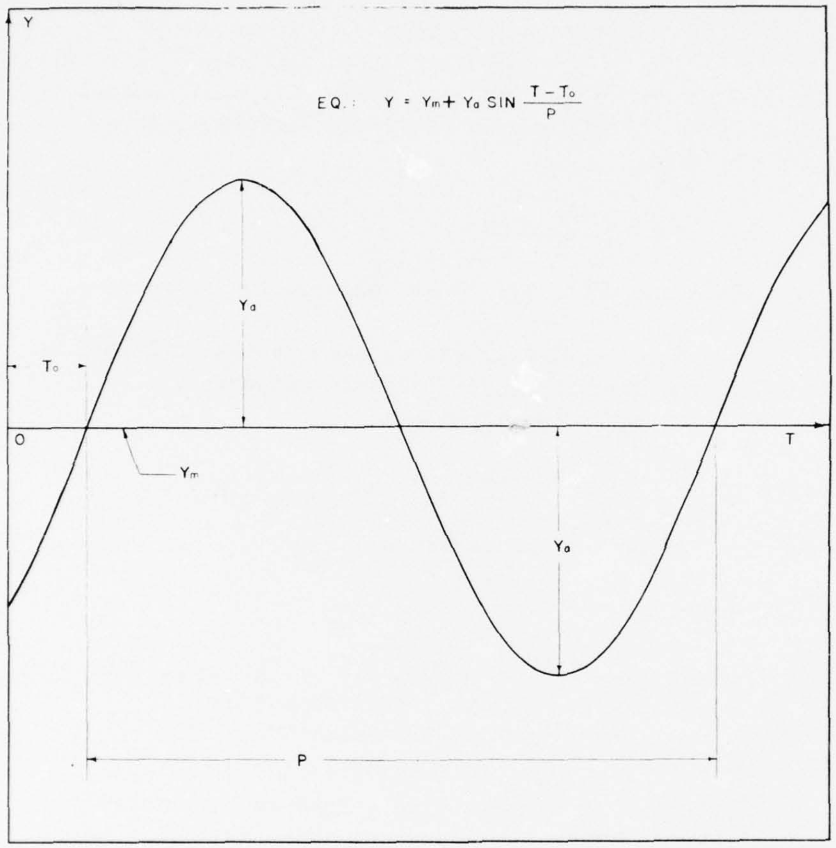
2. For a three-cycle variation, such as that utilized in the analysis of stream quality of the Delaware estuary, the equation has been assumed to have the form:

$$\text{(i) } Y = Y_m + Y_{at} \sin \frac{t_t - t_{ot}}{p_t} + Y_{ad} \frac{\sin t_d - t_{od}}{p_d} + Y_{as} \sin \frac{t_s - t_{os}}{p_s}$$

where:

Y = any stream quality variable (e. g. temp. D O, etc.)
Y_m = a constant equal to predicted average
Y_{at} = a constant equal to the amplitude of the tidal variation of quality variable, Y
t_t = difference between time sample was collected and last maximum flood current time (hours)
t_{ot} = phase angle of tidal cycle
p_t = period of tidal cycle
Y_{ad} = a constant equal to the amplitude of the daily variation of quality variable, Y
t_d = time of day at which sample was collected (hours)
t_{od} = phase angle of daily cycle
P_d = period of daily cycle

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN



ATTACHMENT 2

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE PUBLIC HEALTH SERVICE

FIGURE 1

GENERAL SINE CURVE

Y_{as} = a constant equal to the amplitude of the seasonal variation of quality variable, Y
t_s = time of year sample was collected (days)
t_{os} = phase angle of seasonal cycle
p_s = period of seasonal cycle

3. Obviously, additional and/or different cycles could have been used. However, for purposes of this analysis, the above three cycles were chosen as representing the major portion of the variation observed in a particular stream quality variable.

4. The periods chosen were as follows:

p_t = 12.42 hours
pd = 24.00 hours
ps = 366 days

The value of p_t represents the average length of a tidal cycle in the Delaware estuary. 366 days for the seasonal period was chosen in order to allow for the leap year which occurred during the 9 years of samples which were analyzed. The difference between a period of 365 and 366 days is negligible. A daily period of 24.00 hours is obvious.

5. The form of equation (i) is not amenable for solution since the various constants and phase angles are unknown. Hence, a trigonometric substitution is utilized, e. g. for the tidal cycle:

$$\text{(ii)}\quad Y_{at} \sin \frac{t-t_{ot}}{pt} = Y_{at} \left(\sin \frac{t}{pt} \cos \frac{t_{ot}}{pt}\right) - Y_{at} \left(\cos \frac{t}{p_t} \sin \frac{t_{ot}}{pt}\right)$$

Substituting this identity in equation (i) yields

$$\text{(iii)}\quad Y = Y_m + Y_1 \sin \frac{t_t}{p_t} + Y_2 \sin \frac{t_d}{pd} + Y_3 \sin \frac{t_s}{p_s} + Y_4 \cos \frac{t_t}{p_t} + Y_5 \cos \frac{t_d}{p_d} + Y_6 \cos \frac{t_s}{p_s}$$

where

(iiia) $Y_1, Y_2, Y_3 = Y_{at, d, s} \cos \dfrac{t_{ot, d, s}}{p_{t, d, s}}$

and

(iiib) $Y_4, Y_5, Y_6 = -Y_{at, d, s} \sin \dfrac{t_{ot, d, s}}{p_{t, d, s}}$

6. It is now seen that equation (iii) is entirely in terms known from the observed data except for the values of the constants, Y_m and Y_{1-6}. In order to determine these constants, the concept of "least squares" is utilized.

7. If the constants in equation (iii) were known, a value of Y could be obtained at times t_t, t_d and t_s. This value of Y would deviate from the actual observed value Y by an increment δ.

Hence:

$$\delta = Y - \left(Y_m + Y_1 \sin \frac{t_t}{p_t} + Y_2 \sin \frac{t_d}{p_d} + Y_3 \sin \frac{t_s}{p_s} + Y_4 \cos \frac{t_t}{p_t} + Y_5 \cos \frac{t_d}{p_d} + Y_6 \cos \frac{t_s}{p_s}\right)$$

The method of "least squares" is such that when the values of Y_m and Y_{1-6} are chosen, the sum of the squares of the deviations, δ, are at a minimum. This is done by differentiating with respect to each constant and setting the result equal to zero. Hence, for the constant Y_m:

$$\frac{\partial Y_m}{\partial t} = -2\Sigma \left(Y - Y_m + Y_1, \sin t_t + Y_2 \sin \frac{t_d}{p_d} + Y_3 \sin \frac{t_s}{p_s} + Y_4 \cos \frac{t_t}{p_d} \ldots\right) = 0$$

then,

$$\Sigma Y = Y_m N + Y_1 \Sigma \sin \frac{t_t}{p_t} + Y_2 \Sigma \sin \frac{t_d}{p_d}$$

$$+ Y_3 \Sigma \sin \frac{t_s}{p_s} + Y_4 \Sigma \cos \frac{t_d}{p_d}$$

$$+ Y_6 \Sigma \cos \frac{t_s}{p_s}$$

Similar differentiations can be performed with respect to the remaining constants Y_{1-6}. The end result is the system of seven equations shown in Table A2-1.

8. An examination of these seven equations indicates that the constants Y_m and Y_{1-6} can be obtained by simultaneous solution of the system. All known values are in terms of the observed data, i. e. the actual value of Y and the times t_t, t_d, and t_s are known. If equation (a) of Table A2 - 1 is solved for Y_m it is seen that this constant is equal to the predicted value of the mean and further, is equal to the arithmetic mean of the observed data <u>if</u> the samples had been taken at regularly spaced intervals. This follows from the fact that if t is equally spaced across the period p and the summation is for a full period or multiple thereof, then:

$$\Sigma \sin \frac{t}{p} = 0 = \Sigma \cos \frac{t}{p}$$

Therefore, Y_m tends to compensate for sampling done primarily during one segment of a time period. For example, the arithmetical average (ΣY) of dissolved oxygen samples taken primarily during the summer will be considerably lower than the value Y_m determined from an application of this analysis.

9. The seven equations shown in Table A2-1 can be solved for the constants by a variety of means. For purposes of this study, high speed computing techniques were used both for the computation of the various cross products and the sums thereof and for the actual solutions of the system.

Table A2-1

System of Equations Utilizing Observed Data

(a) $\Sigma Y = Y_m N + Y_1\Sigma(\text{Sin } a) + Y_2\Sigma(\text{Sin } b) + Y_3\Sigma(\text{Sin } c) + Y_4\Sigma(\text{Cos } a) + Y_5\Sigma(\text{Cos } b) + Y_6\Sigma(\text{Cos } c)$

(b) $\Sigma(Y \text{ Sin } a) = Y_m\Sigma(\text{Sin } a) + Y_1\Sigma(\text{Sin}^2 a) + Y_2\Sigma(\text{Sin } a \text{ Sin } b) + Y_3\Sigma(\text{Sin } a \text{ Sin } c) + Y_4\Sigma(\text{Sin } a \text{ Cos } a) + Y_5\Sigma(\text{Sin } a \text{ Cos } b) + Y_6\Sigma(\text{Sin } a \text{ Cos } c)$

(c) $\Sigma(Y \text{ Sin } b) = Y_m\Sigma(\text{Sin } b) + Y_1\Sigma(\text{Sin } a \text{ Sin } b) + Y_2\Sigma(\text{Sin}^2 b) + Y_3\Sigma(\text{Sin } b \text{ Sin } c) + Y_4\Sigma(\text{Sin } b \text{ Cos } a) + Y_5\Sigma(\text{Sin } b \text{ Cos } b) + Y_6\Sigma(\text{Sin } b \text{ Cos } c)$

(d) $\Sigma(Y \text{ Sin } c) = Y_m\Sigma(\text{Sin } c) + Y_1\Sigma(\text{Sin } a \text{ Sin } c) + Y_2\Sigma(\text{Sin } b \text{ Sin } c) + Y_3\Sigma(\text{Sin}^2 c) + Y_4\Sigma(\text{Sin } c \text{ Cos } a) + Y_5\Sigma(\text{Sin } c \text{ Cos } b) + Y_6\Sigma(\text{Sin } c \text{ Cos } c)$

(e) $\Sigma(Y \text{ Cos } a) = Y_m\Sigma(\text{Cos } a) + Y_1\Sigma(\text{Sin } a \text{ Cos } a) + Y_2\Sigma(\text{Sin } b \text{ Cos } a) + Y_3\Sigma(\text{Sin } c \text{ Cos } a) + Y_4\Sigma(\text{Cos}^2 a) + Y_5\Sigma(\text{Cos } a \text{ Cos } b) + Y_6\Sigma(\text{Cos } a \text{ Cos } c)$

(f) $\Sigma(Y \text{ Cos } b) = Y_m\Sigma(\text{Cos } b) + Y_1\Sigma(\text{Sin } a \text{ Cos } b) + Y_2\Sigma(\text{Sin } b \text{ Cos } b) + Y_3\Sigma(\text{Sin } c \text{ Cos } b) + Y_4\Sigma(\text{Cos } a \text{ Cos } b) + Y_5\Sigma(\text{Cos}^2 b) + Y_6\Sigma(\text{Cos } b \text{ Cos } c)$

(g) $\Sigma(Y \text{ Cos } c) = Y_m\Sigma(\text{Cos } c) + Y_1\Sigma(\text{Sin } a \text{ Cos } c) + Y_2\Sigma(\text{Sin } b \text{ Cos } c) + Y_3\Sigma(\text{Sin } c \text{ Cos } c) + Y_4\Sigma(\text{Cos } a \text{ Cos } c) + Y_5\Sigma(\text{Cos } b \text{ Cos } c) + Y_6\Sigma(\text{Cos}^2 c)$

where:

N is the number of times Y is measured
$a = t_t/p_t$ (tidal component)
$b = t_d/p_d$ (daily component)
$c = t_s/p_s$ (seasonal component)

and Y_m, Y_1 through Y_6 are the constants to be solved for.

10. With the constants Y_m and Y_{1-6} obtained , either equation (iii) or equation (i) can be used to determine the value of Y. The use of equation (i) necessitates the solutions of equations (iiia) and (iiib) in order to obtain the amplitudes and phase angles.

11. The significance of the equation itself in terms of the "goodness of fit" of the data, as well as the significance of each individual time cycle can be determined by a variety of standard statistical tests. Among the most important of these statistical tests are the multiple correlation coefficient and the standard errors of the constants Y_{1-6}. The multiple correlation coefficient is of value in determining the overall fit of the equation to the observed data. The coefficient therefore can be used to evaluate the amount of variation in the data which has been removed by the application of the above sinusoidal analysis. Also, the number of individual observations coupled with the correlation coefficient determines the statistical significance of the entire equation.

12. The standard error of the constants obtained by the sinusoidal analysis can be examined and tested statistically to determine the significance of each constant. Statistical significance refers here to the percent probability that a particular result is due to chance alone. For example, a 20% significance indicates that 20 times out of 100 times the result obtained is due to chance alone and 80 times out of 100, the result is a description of the relationship.

13. For purposes of the above analysis, a 5% level of significance has been assumed and results with levels greater than 5% have been considered statistically insignificant. That is, 95 times out of 100 the result obtained is <u>not</u> due to chance alone. With an approach of this kind, the significance of each time cycle can be determined and those cycles with levels of greater than 5% are eliminated from the final equation.

14. There are many additional statistical tests and analyses which can be performed on the results obtained by the sinusoidal analysis, but a detailed description of the use of these tests is beyond the scope of this discussion.

15. With the general equation and the statistical factors governing the use of the equation, an accurate description of the quality of the estuary can then be made.

16. Tables A2-2,3 and 4 present the results of analysis of the above method of the data collected from the Delaware River estuary. Inspection of Table A2-2 indicates that a high degree of correlation and significance was obtained for all the temperature and dissolved oxygen (ppm) results. These variables have been used as the primary indicators of quality conditions in the estuary. In many cases, the results obtained for the other variables tested were still significant; however, these results have not been used due to either (1) inconsistency with what is known to be true, or (2) inconsistency of results within any particular variable. For example, although chlorides were significant in all cases, the amplitudes and phase angles of the seasonal period were not consistent with known physical phenomenon. It is known that in the vicinity of salt water encroachment, chloride concentrations are relatively constant during most of the year and only during low fresh water inflow do the concentrations follow a sinusoidal pattern. The results obtained from an analysis of the BOD data were not used due to their inconsistency. In ten of the twenty-seven analyses performed on the BOD data, the results were not significant at the 5% level. It was felt therefore, that the results obtained did not warrant extensive interpretation. It is believed that these inconsistencies are due in part to the relatively large variability of the BOD test. Although the correlation coefficients obtained from the analyses of the DO in percent saturation are somewhat lower than those obtained from the temperature and DO (in ppm) analyses, statistical significance was maintained in all cases except one. The variations in the DO expressed as percent saturation appear to be greater than those of the temperature coupled with the DO expressed in parts per

TABLE A2-2

MULTIPLE CORRELATION COEFFICIENTS AND SIGNIFICANCE OF FINAL RESULTS

		Cl (ppm)	Temp. (°C)	DO (ppm)	DO (% Sat.)	BOD (ppm)
		117.8 Burlington Bristol Bridge				
West	No. of Samples	111	142	135	132	98
	Correlation Coefficient	.62	.97	.85	.41	.31
	Significance of Results*	< 1%	<1%	<1%	< 1%	< 5%
Center	No. of Samples	307	322	325	321	313
	Correlation Coefficient	.62	.98	.84	.27	.29
	Significance of Results	<1%	<1%	<1%	< 1%	<1%
East	No. of Samples	110	113	101	100	99
	Correlation Coefficient	.61	.97	.87	.39	.25
	Significance of Results	< 1%	<1%	< 1%	< 1%	> 5%
		110.4 Torresdale				
West	No. of Samples	492	562	548	544	99
	Correlation Coefficient	.50	.98	.87	.64	.35
	Significance of Results	<1%	< 1%	< 1%	<1%	< 5%
Center	No. of Samples	325	342	341	338	337
	Correlation Coefficient	.60	.98	.85	.54	.29
	Significance of Results	<1%	< 1%	< 1%	< 1%	<1%
East	No. of Samples	100	100	100	99	100
	Correlation Coefficient	.62	.97	.84	.34	(1)
	Significance of Results	<1%	< 1%	<1%	< 5%	-
		102.2 Lehigh Avenue				
West	No. of Samples	102	101	102	101	102
	Correlation Coefficient	.50	.98	.87	.80	.28
	Significance of Results	<1%	< 1%	<1%	<1%	< 5%
Center	No. of Samples	295	303	306	303	302
	Correlation Coefficient	.57	.98	.88	.79	.37
	Significance of Results	< 1%	<1%	<1%	< 1%	< 1%
East	No. of Samples	98	99	102	99	100
	Correlation Coefficient	.54	.98	.86	.75	.41
	Significance of Results	<1%	<1%	<1%	<1%	< 1%

TABLE A2 -2 (CONTINUED)

		Cl (ppm)	Temp. (°C)	DO (ppm)	DO (% Sat.)	BOD (ppm)
			100.5 Benjamin Franklin Bridge			
	No. of Samples	102	102	102	101	100
West	Correlation Coefficient	.44	.98	.85	.76	.17
	Significance of Results	<1%	<1%	<1%	<1%	>5%
	No. of Samples	350	362	363	359	358
Center	Correlation Coefficient	.46	.98	.87	.78	.31
	Significance of Results	<1%	<1%	<1%	<1%	<1%
	No. of Samples	103	107	102	101	102
East	Correlation Coefficient	.45	.98	.88	.81	.33
	Significance of Results	<1%	<1%	<1%	<1%	<5%
				98.4 Wharton Street		
	No. of Samples	102	103	103	103	102
West	Correlation Coefficient	.51	.98	.83	.76	.12
	Significance of Results	<1%	<1%	<1%	<1%	>5%
	No. of Samples	294	309	309	309	308
Center	Correlation Coefficient	.54	.98	.85	.79	.31
	Significance of Results	<1%	<1%	<1%	<1%	<1%
	No. of Samples	97	113	103	103	103
East	Correlation Coefficient	52	.98	.84	(1)	.59
	Significance of Results	<1%	<1%	<1%	-	<1%
				93.2 Navy Yard		
	No. of Samples	102	103	102	102	102
West	Correlation Coefficient	.49	.98	.84	.77	.20
	Significance of Results	<1%	<1%	<1%	<1%	>5%
	No. of Samples	343	363	361	360	360
Center	Correlation Coefficient	.50	.98	.86	.79	.25
	Significance of Results	<1%	<1%	<1%	<1%	<1%
	No. of Samples	95	102	101	101	101
East	Correlation Coefficient	48	.98	.82	.70	.12
	Significance of Results	<1%	<1%	<1%	<1%	<5%
				84.8 Eddystone		
	No. of Samples	101	102	102	101	101
West	Correlation Coefficient	.52	.98	.81	.71	.27
	Significance of Results	<1%	<1%	<1%	<1%	>5%

TABLE A2 - 2 (CONTINUED)

		Cl (ppm)	Temp. (°C)	DO (ppm)	DO (% Sat.)	BOD (ppm)
	No. of Samples	354	372	369	363	360
Center	Correlation Coefficient	.51	.98	.84	.76	.32
	Significance of Results	< 1%	< 1%	< 1%	< 1%	< 5%
	No. of Samples	96	102	102	101	102
East	Correlation Coefficient	.54	.98	.82	.72	.31
	Significance of Results	< 1%	< 1%	< 1%	< 1%	> 5%
			79.1 Marcus Hook			
	No. of Samples	117	120	107	106	106
West	Correlation Coefficient	.54	.98	.85	.76	.21
	Significance of Results	< 1%	< 1%	< 1%	< 1%	> 5%
	No. of Samples	356	380	380	378	369
Center	Correlation Coefficient	.54	.98	.86	.77	.28
	Significance of Results	< 1%	< 1%	< 1%	< 1%	< 1%
	No. of Samples	117	121	109	108	109
East	Correlation Coefficient	.59	.98	.82	.66	.29
	Significance of Results	< 1%	< 1%	< 1%	< 1%	> 5%
	No. of Samples	316	342	47	47	48
Center**	Correlation Coefficient	.60	.98	.89	.96	.73
	Significance of Results	< 1%	< 1%	< 1%	< 1%	< 1%
			71.6 Cherry Island			
	No. of Samples	70	71	72	70	60
Center	Correlation Coefficient	.59	.96	.70	.70	.65
	Significance of Results	< 1%	< 1%	< 1%	< 1%	< 1%
			66.8 New Castle			
	No. of Samples	46	49	51	49	43
Center	Correlation Coefficient	.58	.95	.61	.66	.64
	Significance of Results	< 1%	< 1%	< 1%	< 1%	< 1%

Note: All values are top values unless otherwise noted

* < 1% = Highly Significant)
< 5% = Significant) See Glossary page for definition
\> 5% = Not Significant) of significance

** Bottom Values

(1) No correlation obtained

TABLE A2-3
TEMPERATURE VARIATIONS IN
(Degrees

Sta. Mile Point and Name	Cross* Section	Number of Samples	Predicted Grand Average	Average Seasonal Variation Min.	Max.	Time of Min. (Days)	Time of Max. (Days)	Item No.
117.8	West	142	14.3	1.9	26.8	26	208	1
Burlington-Bristol	Center	322	13.3	0.5	26.2	25	207	
Bridge	East	113	15.3	2.4	28.2	23	205	
110.4	West	562	14.2	1.9	26.6	29	211	2
Torresdale	Center	342	15.2	2.6	27.9	26	208	
	East	100	17.0	4.2	29.8	25	207	
102.2	West	101	14.8	2.3	27.2	27	209	3
Lehigh Avenue	Center	303	13.5	0.7	26.3	27	209	
	East	99	14.1	1.3	26.9	28	210	
100.5	West	102	13.6	1.1	26.1	28	210	4
Ben Franklin	Center	362	13.4	0.7	26.1	28	210	
Bridge	East	107	12.9	0.1	25.7	27	209	
98.4	West	103	11.9	0.0	24.5	29	211	5
Wharton Street	Center	309	12.1	0.0	24.9	28	210	
	East	103	11.7	0.0	24.6	28	210	
93.2	West	103	11.8	0.0	23.8	29	211	6
Navy Yard	Center	364	11.6	0.0	24.0	29	211	
	East	102	10.6	0.0	23.2	28	210	
84.8	West	102	16.2	3.7	28.7	28	210	7
Eddystone	Center	372	13.5	1.0	26.0	28	210	
	East	102	14.0	1.4	26.6	28	210	
79.1	West	120	14.6	2.4	26.8	27	209	8
Marcus Hook	Center	380	13.1	0.7	25.4	29	211	
	Center***	342	15.0	2.9	27.2	29	211	
	East	121	14.0	2.0	26.5	28	210	
71.6								9
Cherry Island	Center	71	15.2	3.9	26.5	27	209	
66.8								10
New Castle	Center	49	15.0	4.1	25.9	27	209	

* Values are for surface only, unless otherwise noted
** Time in hours after maximum flood current time
*** Bottom values

DELAWARE RIVER ESTUARY
Centigrade)

Item No.	Average Daily Variation Min.	Max.	Time of Min. (Hours)	Time of Max. (Hours)	Average Tidal Variation Min.	Max.	Time of Min.** (Hours)	Time of Max.** (Hours)
1	13.1	15.5	6.6	18.6		not significant		
		not significant			13.0	13.7	9.8	3.6
		not significant				not significant		
2	13.7	14.8	9.9	21.9		not significant		
		not significant			15.0	15.5	9.8	3.6
		not significant				not significant		
3		not significant				not significant		
		not significant			13.1	13.9	8.3	2.1
		not significant			13.6	14.6	8.3	2.1
4		not significant			13.2	14.0	9.3	3.1
	12.3	14.5	23.8	11.8	13.0	13.8	9.3	3.1
		not significant			12.3	13.5	8.9	2.7
5	8.1	15.6	9.0	12.0		not significant		
	8.9	15.3	0.1	12.1		not significant		
	8.2	15.1	0.2	12.2		not significant		
6	8.4	15.3	0.2	12.2		not significant		
	8.1	15.0	0.3	12.3	11.2	11.9	9.5	3.3
	6.0	15.2	0.2	12.2		not significant		
7		not significant				not significant		
	11.9	15.1	2.3	14.3	13.2	13.8	9.1	2.9
	12.6	15.4	3.9	15.9		not significant		
8		not significant				not significant		
	11.3	14.8	23.9	11.9		not significant		
		not significant				not significant		
		not significant				not significant		
9								
		not significant			13.7	16.6	12.2	6.0
10								
		not significant			13.7	16.4	12.2	6.0

TABLE A2-4
DISSOLVED OXYGEN VARIATIONS
(Parts per

Sta. Mile Point and Name	Cross* Section	Number of Samples	Predicted Grand Average	Average Seasonal Variation Min.	Max.	Time of Min. (Days)	Time of Max. (Days)	Item No.
117.8	West	135	7.6	4.5	10.7	213	30	1
Burlington-Bristol	Center	325	9.4	6.4	12.4	209	26	
Bridge	East	101	5.0	1.8	8.2	211	28	
110.4	West	548	7.8	4.1	11.5	219	36	2
Torresdale	Center	341	7.2	4.0	10.4	215	32	
	East	100	7.3	4.3	10.3	203	20	
102.2	West	102	6.2	1.6	10.8	223	40	3
Lehigh Avenue	Center	306	7.2	2.6	11.8	229	46	
	East	102	7.4	2.0	10.8	229	46	
100.5	West	102	5.0	0.9	9.2	226	43	4
Ben. Franklin	Center	363	5.5	1.0	10.0	228	45	
Bridge	East	102	6.2	1.7	10.7	229	46	
98.4	West	103	5.2	1.0	9.4	226	43	5
Wharton Street	Center	309	5.4	0.9	9.8	228	45	
	East	103	5.5	1.1	9.9	228	45	
93.2	West	102	7.7	3.8	11.6	224	41	6
Navy Yard	Center	361	6.7	2.7	10.7	230	47	
	East	101	6.1	2.4	9.8	227	44	
84.8	West	102	6.1	2.8	9.4	220	37	7
Eddystone	Center	369	5.1	1.7	8.5	215	32	
	East	102	5.3	1.8	8.7	225	42	
79.1	West	107	5.3	1.8	8.8	211	28	8
Marcus Hook	Center	380	4.0	0.6	7.4	217	34	
	East	109	4.4	1.2	7.6	218	35	
71.6								9
Cherry Island	Center	72	5.7	4.1	7.3	185	02	
66.8								10
New Castle	Center	51	5.4	4.3	6.5	138	320	

* Values are for surface only.
** Time in hours after maximum flood current time.

IN DELAWARE RIVER ESTUARY
Million)

Item No.	Average Daily Variation Min.	Max.	Min. (Hours)	Max. (Hours)	Average Tidal Variation Min.	Max.	Time of Min.** (Hours)	Time of Max.** (Hours)
1	5.9	9.3	20.7	8.7		not significant		
	8.4	10.4	15.7	3.7	9.1	9.7	3.1	9.3
	1.1	8.9	22.8	10.8	4.6	5.4	2.4	8.6
2	7.1	8.5	20.3	8.3	7.4	8.2	2.8	9.0
	6.0	8.4	22.5	10.5	6.0	8.4	2.0	8.2
		not significant			6.8	7.8	1.4	7.6
3		not significant			5.6	6.8	2.3	8.5
	5.8	8.6	12.5	0.5	6.2	8.2	2.2	8.4
		not significant			5.4	7.4	2.0	8.2
4		not significant			4.5	5.6	2.9	9.1
		not significant			4.7	6.3	3.3	9.5
		not significant			5.8	6.6	2.9	9.1
5		not significant			4.8	5.6	5.9	12.1
		not significant			5.1	5.6	4.4	10.6
		not significant				not significant		
6	3.9	11.5	11.4	23.4		not significant		
	4.4	9.0	11.4	23.4		not significant		
		not significant				not significant		
7		not significant				not significant		
		not significant			4.9	5.3	9.3	3.1
		not significant				not significant		
8		not significant			4.8	5.8	9.3	3.1
	3.0	5.0	21.5	9.5	3.6	4.4	9.9	3.7
		not significant			4.0	4.8	8.9	2.7
9								
	4.2	7.2	11.2	23.2	5.0	6.4	8.7	2.5
10								
		not significant			3.9	7.0	12.3	6.1

million. The relatively larger variation may be expected since for any value of DO in ppm, the percent saturation may vary considerably depending on the temperature. Also, for the same percent saturation value, the DO in ppm and the temperature may vary considerably. Apparently, the combination of events relating the DO in ppm and the temperature is such that the resulting percent saturation values do not follow a sinusoidal pattern as well as the DO in ppm and the temperature.

17. Table A2-2 indicates that the sinusoidal analyses performed on the temperature data consistently yielded multiple correlation coefficients greater than 0.95 indicating the high degree of resolution of the temperature variation. Table A2-3 presents the details of the results obtained from the analyses the temperature data. From this Table, the temperature at any time of year, day or tide can be predicted. For example, at the center of the estuary at Benjamin Franklin Bridge the maximum average daily temperature during the year is 26.1°C. occurring on the 210th day or July 29. This value represent the maximum average daily temperature with the variation within the day and across the tide held at the predicted grand average of 13.4°C* Hence, 12.7°C.(=26.1° -13.4°) is the maximum amplitude of the water temperature during a year with the daily and tidal components at the predicted average level. In order to determine the maximum effect of the time of day or tide on this maximum temperature of 26.1°C., the amplitudes of these respective cycles are added to this value. Thus at approximately twelve noon, the maximum amplitude within a day is reached and is equal to 0.9°C (=14.5° -13.4°). Also at approximately three hours after maximum flood current time, (equal to slack flood current time) maximum temperature amplitude within a tidal cycle is reached and is equal to 0.4°C (=13.8° -13.4°). Figure 17 of Part B presents these relationships in graphical form. Therefore, the maximum temperature to be expected at the center at Benjamin Franklin Bridge is 27.4°C. (=26.1° +0.9° + 4°) and occurs on July 29

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* The predicted grand average represents the average which would have occurred had samples been collected continuously for the period of record. It differs from the arithmetic mean of the available data by the extent of the sampling bias.

at twelve noon during the time of slack flood current. This does not infer that if one sample were taken under these conditions the tempera- would necessarily be exactly 27.4°C. Rather, if a sufficiently large number of samples were taken during these times, the average of these samples would be 27.4°C.

18. Table A2-2 indicates the significance of the results of the analyses performed on the DO in ppm. In all cases the statistical significance remained below the 1% level. Table A2-4 presents the details of the results obtained from the DO analyses. The form of this Table is the same as in Table A2-3 and the above discussion also applies except that for the DO the minimum values are of primary concern. Thus at the center at Benjamin Franklin Bridge, minimum average daily DO during a year is 1.0 ppm and occurs on the 228th day (August 16), 18 days later than the maximum temperature. The variation within a day at this station was computed to be statistically non-significant. During a tidal cycle, minimum DO occurs at approximately three hours after maximum flood current time and is equal to 4.7 ppm or an amplitude of 0.8 ppm (=5.5-4.7). Hence, during the minimum average day (August 16) at slack flood tide, the DO drops to 0.2 ppm (=1.0 -0.8). Again, this value would not necessarily be obtained if only one sample was taken on the 228th day at slack flood tide. If a number of samples were collected under these conditions the average of the values would equal 0.2 ppm. From Table A2-4, the DO at various points in the estuary can be described for any given time of year, day or tide.

19. In summary, the sinusoidal analysis provided accurate results describing the temperature and DO variations in the estuary. The results obtained from the analyses of the chloride and BOD data were not consistently significant and their extensive interpretation was not undertaken. These variables apparently do not vary according to the original sinusoidal assumption.

REPORT ON THE

COMPREHENSIVE SURVEY

OF THE

WATER RESOURCES

OF THE

DELAWARE RIVER BASIN

APPENDIX D

FLOOD DAMAGES

PREPARED BY THE
U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.

REPORT ON THE COMPREHENSIVE SURVEY
OF THE
WATER RESOURCES OF THE DELAWARE RIVER BASIN

APPENDIX D - FLOOD DAMAGES

CONTENTS

CONTENTS (Continued)

TABLES

Table Number

PLATES

APPENDIX D

FLOOD DAMAGES

1. SCOPE. This appendix delineates principal areas subject to flooding and reports on results of flood damage surveys and studies. It presents supporting data used as a basis for estimating flood damages and gives typical basic data, computations and curves to permit an understanding of the procedures used in the determination of average annual flood damages.

2. AREAS SUBJECT TO FLOODING. There are two distinct areas subject to flooding in the Delaware basin, the upper or non-tidal area which includes the main stem and tributaries of the Delaware River above Trenton, New Jersey, and the lower or tidal area which includes the Delaware River and Bay from Trenton to the Delaware Capes. Floods in the upper area are caused by storms which traverse the basin; while floods in the tidal section are caused by flows emanating from the upper river, spring tides resulting from tidal fluctuations, wind tides produced by hurricanes or storm action, or from a combination of two or more of these phenomena. In this report the limits of tidal influence on flooding are considered as Burlington, New Jersey, on the Delaware River, Fairmount Dam, Philadelphia on the Schuylkill River, and Wilmington, Delaware, on the Christina River. These limits were determined from high water profiles, flood frequency studies, and flood damage field surveys, utilized in connection with the investigation by the U. S. Army Engineer District, Philadelphia on the effect of hurricanes on flood stages in the Delaware Bay region. The extent and character of flooded areas are discussed in subsequent paragraphs, as are urban damage centers which have experienced sufficient flood damages to warrant investigations for local flood protection projects. All damage values presented in paragraphs 3 to 13, inclusive, are based on August 1955 price levels. Detailed descriptions of flooded areas in urban damage centers are given in table 1. Plate 1 shows the locations of these urban damage centers.

3. Delaware River. The area subject to flooding in the upper reach of the river from Hancock, New York, to Port Jervis, New York, consists of an extremely narrow valley with little development along the banks of the stream. Property damage resulting from flooding is relatively minor in this reach, and occurs generally to a double track line of the Erie Railroad, one major highway, and to the cities of Port Jervis, New York, and Matamoras, Pennsylvania, which lie in the flood plain. The reach from Port Jervis to the Delaware Water Gap flows through a wider valley having a flood plain averaging 1,200 feet in width. Flooding in this reach is confined to scattered residences and summer cottages on both banks and to several small communities including Shawnee-on-Delaware, Pennsylvania. The remainder of the

non-tidal section from the Delaware Water Gap to Trenton, New Jersey, has a flood plain averaging 1,600 feet in width. The 1955 flood losses in this section exceeded 85 percent of the total damage for the main stem of Delaware River, and occurred principally at the damage centers of Belvidere, Pennsylvania, Phillipsburg, New Jersey, Easton, Pennsylvania, Riegelsville, Pennsylvania, New Hope, Pennsylvania, Yardley, Pennsylvania, Trenton, New Jersey, and Burlington, New Jersey. The extent and character of the area subject to flooding in the reach from Port Jervis to Trenton are shown in table 2. Flood damage along the main stem of Delaware River amounted to approximately 40 million dollars in August 1955, two-thirds of which occurred in urban damage centers.

4. East Branch Delaware River. The East Branch Delaware River, at the headwaters of the Delaware River basin, drains 840 square miles of mountainous area in southeastern New York State. Substantial flood losses have occurred at the damage centers of Margaretville, New York, located just below the confluence of Bush Kill and East Branch Delaware River; at Livingston Manor, New York, located at the confluence of Little Beaver Kill and Cattail Brook with Willowemoc Creek; at Roscoe, New York, located on the right bank of Willowemoc Creek about 1/4 mile upstream of the confluence of Willowemoc Creek with Beaver Kill; and at Rockland, New York, located on Beaver Kill about one mile north of Roscoe. Flood damages along the steep sided streams in the watershed are minor except at these damage centers. Pepacton Reservoir, constructed by the New York Board of Water Supply and completed in 1955, is located on the East Branch Delaware River approximately two miles above Downsville, New York. Since water supply is the primary purpose of this project, it provides only incidental beneficial effects on downstream flooding.

5. West Branch Delaware River. The West Branch Delaware River, located in the headwaters of the Delaware River basin, drains 664 square miles of mountainous area in southeastern New York State. The narrow valleys of the watershed are sparsely populated except for a few scattered towns, and flood damages are comparatively minor. Cannonsville Reservoir, under construction by the New York Board of Water Supply, is located on the West Branch Delaware River approximately two miles above Stilesville, New York. This water supply project will provide only incidental beneficial effects on downstream flooding.

6. Lackawaxen River. The Lackawaxen River drains an area of 588 square miles in the extreme northeastern part of Pennsylvania, where numerous glaciated lakes and steeply sloping watersheds contribute to frequent flash flooding. Flood plains along the Lackawaxen River vary from narrow gorges to narrow valleys having widths up to 1/2 mile. The towns of Honesdale, Pennsylvania, located at the confluence of Lackawaxen River and Dyberry Creek, and Hawley, Pennsylvania, located

at the junction of Middle Creek and Lackawaxen River, suffered damages amounting to $415,000 and $900,000, respectively, from the August 1955 flood. Several villages and seven townships located in the lower reaches of Lackawaxen River have residential, commercial, utility, highway and other developments on the flood plain, and experienced one and one-half million dollars in flood damage in 1955. Two flood control reservoirs are now under the jurisdiction of the Corps of Engineers; one, under construction, near Prompton, Pennsylvania, on Lackawaxen River, and the other, completed, above Honesdale, Pennsylvania, on Dyberry Creek. A stream channel rectification project at Honesdale and a local protection project at Hawley constructed by the Pennsylvania Department of Forests and Waters together with the two flood control projects under the jurisdiction of the Corps of Engineers will virtually eliminate flood water damage along the Lackawaxen River from the dam sites to Hawley, Pennsylvania. In addition, seven flood water retarding dams planned by the Soil Conservation Service, three of them now under construction, will substantially reduce flood damages on five small tributary streams entering the Lackawaxen River between Honesdale and Hawley. Flood damages on Wallenpaupack Creek, a tributary of Lackawaxen River, amounted to over two million dollars in 1955, most of which occurred in Greentown, Newfoundland and South Sterling, Pennsylvania, and in adjacent townships. Flooding in the lower Lackawaxen River below Hawley and downstream on Delaware River was considerably reduced by the operation of the Pennsylvania Power and Light Company's hydroelectric dam on Wallenpaupack Creek approximately two miles upstream from its confluence with Lackawaxen River.

7. Neversink River. The Neversink basin is thinly populated. About 85 percent of the basin is mountainous woodland, unsuited for agriculture. Its valley is relatively narrow with steep sides except in the first 10 miles above Port Jervis, New York, where it widens to about 2,000 feet to form the major area subject to flooding on the Neversink River. In this lower reach, some 10 farms, several small communities of summer cottages and about 150 residences located at Myers Grove are subject to the hazards of flooding. Minor flood damage also occurs in the vicinity of Deer Park, about 14 miles above the mouth of Neversink River. A major highway and an abandoned railroad bed, located in the flood plain of this reach, are subject to only minor flood damages. The Neversink Reservoir, located about 41 miles above the mouth, diverts part of the streamflow for New York City water supply. Since flood control was not a feature of this development, the reservoir provides only a limited measure of protection against floods. Flooding along Neversink tributaries is extensive, especially in Monticello and South Fallsburg, New York, located on Tannery Brook and at the head of Pleasure Lake, respectively.

8. Brodhead Creek. Brodhead Creek enters the Delaware River from the west approximately two miles above Delaware Water Gap. Including its principal tributaries, McMichael, Pocono and Paradise

Creeks, it drains an area of 285 square miles mostly in Monroe County, Pennsylvania. Railroads and numerous highways traverse the area, following creek banks in many instances, and are subject to severe flood damage. Over 40 highway and railroad bridges were washed out during the 1955 flood which was by far the most extensive and destructive known in the history of the Brodhead. Twenty-five lives were lost in Stroudsburg and East Stroudsburg, Pennsylvania, thirty-seven people lost their lives at Camp Davis, a summer camp for children just above Stroudsburg, and eight lives were lost in other parts of the basin as a result of the flood. Flood losses were extremely severe in the boroughs of Stroudsburg, East Stroudsburg, Canadensis and Tannersville, Pennsylvania. Flood damages in 1955 at Stroudsburg and East Stroudsburg amounted to over 6 million and 4 million dollars, respectively. A local protection project, currently being designed by the Commonwealth of Pennsylvania, will protect Stroudsburg and East Stroudsburg from a flood of the August 1955 magnitude. Canadensis, located in a narrow valley on Brodhead Creek, 22 miles above the mouth, had damages amounting to $304,000 in 1955. The August 1955 flood damages at Tannersville, located on Pocono Creek about 10 miles upstream from Stroudsburg, exceeded $330,000.

9. Lehigh River. Flood heights and damages will be reduced substantially by three flood control projects under construction by the Corps of Engineers and one flood control project recently completed by the Commonwealth of Pennsylvania on the Lehigh River. The projects are: (1) a flood control reservoir located near the mouth of Bear Creek, which will reduce flood heights on the Lehigh River from the dam site to the mouth, (2) a channel improvement project, near completion, at Allentown, Pennsylvania, (3) a local protection project at Bethlehem, Pennsylvania, and (4) the completed local protection project at Weissport, Pennsylvania. The flood plain of the Lehigh River is narrow and steep sided above Lehigh Gap, 35 miles above the mouth. Flooding in this upper reach has occurred in the towns of Jim Thorpe, Lehighton, Weissport, Parryville, Palmerton and Bowmanstown, Pennsylvania. Weissport has been subject to the greatest amount of flooding with about 45 acres of the community inundated to an average depth of five feet by both the May 1942 and the August 1955 floods. Below Lehigh Gap both the river and flood plain widen. Highways in the basin are generally located above the flood plain. However, the railroad beds, frequently located in the flood plain, and the 44 railroad and highway bridges spanning the Lehigh River are subject to recurring flood damage. The Lehigh Navigation Canal, which extends from Jim Thorpe to Easton, Pennsylvania, was inundated at numerous places by the major floods of 1902, 1942 and 1955, with accompanying extensive flood damages. In the reach from Lehigh Gap to Allentown, Pennsylvania, approximately 225 acres lie in the flood plain, including about 90 acres of industrial and residential area located in the towns of Northampton, Hokendauqua and Catasauqua, Pennsylvania. In the vicinity of Allentown some 380 acres are subject to flooding, including 300

acres occupied by commercial and industrial establishments and 80 acres of residential area. In the vicinity of Bethlehem and Freemansburg, Pennsylvania, the flooded area consists of approximately 540 acres including 150 acres of Bethlehem Steel Company plant, and over 100 acres of residential area, public parks, railroad yards, and main line tracks. The extent of flooding at West Easton and Easton, Pennsylvania, depends not only on the flows emanating from the Lehigh River, but also on the Delaware River flows. This condition is illustrated by a comparison of the 1942 and 1955 floods at Easton. Although these floods were similar in magnitude on the Lehigh, as indicated by stage and discharge records at Bethlehem, flood heights at Easton were 10 to 15 feet higher in 1955 than in 1942. This was due to backwater effect on the Lehigh caused by the extreme flood of 1955 on the Delaware.

10. Schuylkill River. Due to the steep slopes and narrow valleys of the Schuylkill River and its tributaries, the flood plains are generally limited in extent throughout the basin. On the main stem, from Philadelphia to Port Clinton, Pennsylvania, the flood plain is estimated to average 500 feet in width, and above Port Clinton to vary from 200 to 300 feet in width. Upstream from the gap where the river passes through Blue Mountain, the headwaters region is traversed by three branches: West Branch Schuylkill River, Schuylkill River, and Little Schuylkill River. The greatest flooding in this region in August 1955 occurred in the Little Schuylkill basin, with exceptionally severe damages at Tamaqua, Pennsylvania, located at the confluence of Wabash Creek and Panther Creek with the Little Schuylkill River. A large part of Tamaqua is built in a narrow valley and the streams, which flow through the city, are generally inadequate to carry the flood runoff. The 1955 flood damages at Tamaqua amounted to more than $930,000. Approximately 5.5 miles below Tamaqua at Reynolds, Pennsylvania, the Atlas Powder Company experienced extremely heavy flood damage in August 1955. A watershed work plan, prepared by the Soil Conservation Service under Public Law 566, proposes three flood water retarding structures above Tamaqua, Pennsylvania, one flood water retarding structure above New Ringgold, Pennsylvania, on Koenig's Creek, and local channel work in the vicinity of Reynolds, Pennsylvania. On the West Branch Schuylkill River flooding has been infrequent and only minor flood damages have occurred at the towns of Schuylkill Haven, Pottsville and Port Carbon, Pennsylvania. From Blue Mountain downstream to Reading, Pennsylvania, the flood plain is generally unoccupied between centers of population because the sterile mantle of culm and silt covering the soil has greatly reduced the value of these agricultural lands. Flood damages in this reach are also experienced at Kutztown, Pennsylvania, where the area subject to flooding extends through the borough along both banks of Sacony Creek. Below Reading, the floodway is occupied mostly by commercial and industrial interests which suffered about 70 percent of the total flood damages in this area in August 1955. The greatest degree of flooding in this reach is

experienced at Reading, Birdsboro, Pottstown, Norristown, Conshohocken, Manayunk and Philadelphia, Pennsylvania. The 1955 flood damages at Reading, located on the left bank of the Schuylkill River opposite the mouth of Tulpehocken Creek, about 60 miles upstream from Philadelphia, amounted to $223,000, and occurred in a low area of industrial and residential properties. The 1955 flood damages at Birdsboro, located on the right bank of the Schuylkill River, 63.5 miles above the mouth, and at Pottstown and South Pottstown, located on the left and right banks of the Schuylkill River at the mouth of Manatawny Creek, amounted to $82,500 and $342,000, respectively. Although the 1955 flood was not particularly severe on the Schuylkill River at Norristown, there was considerable flooding by two local tributaries, Stony Creek and Saw Mill Run, which flow through the city. The area inundated at Norristown in August 1955 included 40 acres by the Schuylkill River, 70 acres by Saw Mill Run, and 85 acres by Stony Creek. The area subject to flooding by high flows of the Schuylkill River within the city limits of Philadelphia extends from Manayunk to Fairmount Dam. Although only Fairmount Park in Philadelphia had flood damages in August 1955, large sections of low-lying residential, commercial, and industrial properties in Manayunk and East Falls would have been seriously damaged by flood stages only slightly higher than those which occurred.

11. Secondary roads within the Schuylkill River flood plain are subject to inundation and occasional interruption of their use by deposits of silt and debris. Generally, railroads and main highways, including bridges, have been located and constructed so that they will not be seriously threatened by flooding; consequently flood damages to railroads and highways have been relatively minor in the past. Flood damages on most of the tributaries of the Schuylkill River have been of infrequent occurrence and small in amount. Along some of these tributaries, as well as the lower reaches of the main river, summer cottages are located close to the riverbanks and are subject to flooding and damages from extreme floods. A culm removal project carried on jointly by the Commonwealth of Pennsylvania and the Federal government was completed in October 1954. Although this project has considerably improved the channel and water quality of the Schuylkill River, its value in reducing flood stages is localized and quite limited.

12. Christina River. The Christina River has developed a wide, flat valley in the lower three-quarters of its length, while in the upper quarter the valley is narrow. The flood plain, over a mile in width in the lower tidal marshes, narrows to 100-200 feet above Newark, Delaware. Flood damage along the Christina River proper is usually not extensive. However, some flood damage, ordinarily due to high tides, occurs at Wilmington, Delaware, near the junction of Christina River and Brandywine Creek. Brandywine Creek, the principal tributary of the Christina River, has a drainage area of about 300

square miles, mostly in Chester County, Pennsylvania. The Brandywine flood plain includes some agricultural land affected by flooding plus urban flooding in Wilmington, Delaware, and Coatesville and Downingtown, Pennsylvania. Virtually all of the area subject to flooding at Coatesville, located 35 miles upstream from Wilmington, is occupied by the Lukens Steel Company's plant which experienced approximately 1/4 million dollars flood damages in August 1955. Downingtown, located on the East Branch Brandywine Creek, which flows through the town, experienced approximately $170,000 flood damages in 1955. A comprehensive plan for developing the water resources of the upper Brandywine basin has been developed jointly by the Soil Conservation Service, the Pennsylvania Department of Forests and Waters, the Pennsylvania Fish Commission, and the local people of the Brandywine Watershed. This plan proposes six single-purpose flood prevention dams, four multipurpose dams with flood prevention storage, and a channel improvement project on Sucker Run in the western section of Coatesville. Flooding at Wilmington results from flood flows emanating in the upper reaches of Brandywine Creek and from hurricane effects on tidal fluctuations in the lower Delaware River and bay areas. Although flood damages in Wilmington were relatively minor in August 1955, the area subject to inundation is extensive and serious losses would result from floods of greater magnitude. Flood damages resulting from the August 1955 flood on White Clay and Red Clay Creeks, two other tributaries of the Christina River, were also minor. The greatest flood of record on White Clay Creek occurred on 5 July 1937. This flood was caused by a local storm covering an area of approximately 25 square miles southwest of Wilmington. According to U. S. Geological Survey Water Supply Papers the maximum stage at the gage downstream from Newark, Delaware, during this flood was about seven feet higher than the 1955 flood. It further states that the gage was probably affected by backwater from the Baltimore & Ohio Railroad bridge, approximately 300 feet downstream, which has since been raised and widened. Most of the damages from this flood resulted from high flows in the tributary streams and local flooding associated with intense rainfall.

13. Smaller Streams Tributary to the Delaware River. The flood plain areas along most of the smaller tributary streams of the Delaware River are relatively narrow and generally sparsely populated. Consequently, most of the flood losses are rural in character, with some urban flood losses occurring at damage centers located in the narrow valleys. Frequent flooding experienced along the narrow valley of Paulins Kill has resulted in considerable damage at Blairstown, Newton and Branchville, New Jersey. As a result, the Department of Agriculture has developed a work plan for Paulins Kill which includes flood protection projects at Blairstown and Newton. Flooding at Branchville in 1955 was caused by the failure of two dams above the town and will not recur. Frequent flooding on Neshaminy Creek causes damage at the rapidly developing residential areas in the boroughs of Langhorne Terrace, Parkland, Hulmeville, Newportville, and Chalfont,

Pennsylvania. Urban damage centers located on the smaller tributaries are also described in table 1 and shown on plate 1. Other flood damage centers exist in the basin, particularly in and around the suburban areas of Trenton, New Jersey, Camden, New Jersey, Philadelphia, Pennsylvania, and Wilmington, Delaware. These centers are not well defined in many instances and have been omitted from this discussion since they will not be affected by any proposed flood control projects. The character and extent of flooding of rural areas along the minor tributary streams is discussed in Appendix R which outlines the role of the small dams and reservoirs in the comprehensive plan for the development of the water resources in the Delaware River basin.

14. FLOOD DAMAGE REACHES. The Delaware River, its principal tributaries, and some of the minor tributaries have been divided into convenient stream reaches. For planning purposes and for use in determining justification for flood control structures, the reach limits were selected so that damages within each reach could be correlated with stage-discharge and discharge-frequency relations for a reference gage in the reach. The reaches were also selected so that they could be readily grouped to define adequately damages that would be modified by the several projects in the proposed water resources development plan. The damage reaches selected for study are shown on plate 2 and are described in table 8. Minor tributaries and extreme headwater reaches where flood losses were insignificant or where no flood control projects were contemplated were not included in the evaluation of average annual flood damages. River mileage, used in describing reach limits, is measured from the mouth of each stream, except mileage on the Delaware River which is measured from the Capes.

15. Delaware River. The reaches of the Delaware, beginning at the confluence of the East and West Branches near Hancock, New York, are designated in a downstream order and extend through Burlington, New Jersey. Flood damages in the reach below Burlington are due to tidal fluctuations, and were not included in the evaluation of average annual damages which could be prevented or alleviated by upstream flood control measures.

16. Lehigh River. In order to simplify the analysis, the reaches along the Lehigh River combine the zones used in connection with previous economic justification studies made for Bear Creek Reservoir, for the Bethlehem, Pennsylvania local protection project, and for the Allentown, Pennsylvania channel rectification project. These reaches cover the length of the Lehigh River from Easton, Pennsylvania, to just above Bowmanstown, Pennsylvania. Reach 1, located in Easton at the confluence of the Lehigh River with the Delaware River, has been included in the Delaware River reach, C-2a.

17. Lackawaxen River. The Lackawaxen River reaches or zones above Hawley, Pennsylvania, are the same as those used in connection

with the previous economic justification studies made for the Prompton and Jadwin flood control reservoirs. A reach extending from Hawley to the mouth of Lackawaxen River was added for this report.

18. Schuylkill River. The Schuylkill River reaches are numbered in an upstream order from the mouth. Reach 0, which is affected by tidal fluctuations, includes a portion of Philadelphia from the mouth of Schuylkill River to Fairmount dam. The uppermost reach extends to just above Middleport, Pennsylvania, on the Schuylkill River.

19. Other Tributary Streams. Damage reaches were designated on other tributary streams where field investigations indicated flooded areas with moderate to high damage potential. These reaches are also shown on plate 2 and described in table 8.

20. CLASSIFICATION OF FLOOD DAMAGES. Flood losses or damages are designated by classes and types of damage indicated in paragraphs 21 to 24 inclusive, and were developed in accordance with terminology contained in paragraph 1-72 of EM 1120-2-101 1/ and paragraph 3 of EM 1120-2-112. 2/

21. Tangible Damages. The average annual damages which might result from future floods were determined for the damage reaches described in table 8 and shown on plate 2 and reflect the tangible recurring damages determined from field surveys of flood losses. Tangible damages are considered as follows: (1) physical damages caused by inundation, (2) emergency losses or costs incurred in anticipation of or fighting the flood, termed "flood fighting costs" in this report, and (3) business or other financial losses resulting from decreased production, profits and wages, and increased cost of normal operations and living. The elimination of such damages constitutes primary benefits. Tangible damages were determined in the field surveys for the following classes or types of flood losses:

Residential damages include inundation losses to nonfarm residences and contents thereof, appurtenant buildings, and grounds. Residential business losses refer to rental of other living quarters and to increased cost of meals and other services while away from home due to the flood. Residential flood fighting losses, the costs incurred

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1/ Examinations and Surveys - General Procedures, Department of the Army, Office of the Chief of Engineers, Preliminary Engineering Manual for Civil Works Construction, Part CI, chapter 1, change 3, 28 April 1958.

2/ Examinations and Surveys - Terminology of Economic Evaluation, Department of the Army, Office of the Chief of Engineers, Preliminary Manual for Civil Works Constructions, Part CI, chapter 2, 10 September 1957.

in anticipation of and in fighting the flood, are included in estimates of tangible flood damages.

Commercial damages include losses to all those properties used in commerce, business, trade, servicing or entertainment as distinguished from other properties used in industry, manufacturing, mining, navigation, public administration, utility production and service, and transportation. Physical flood damages to commercial property and facilities include damages to land, buildings, equipment, supplies, merchandise and other items used in the conduct of the business. Business losses, sustained by commercial activities as a consequence of floods, result from net losses of business income and loss of wages to employees. Net loss of business income includes losses resulting from decreased production, loss of sales or services normally required by the consuming public, or the loss of a net profit to the owner of a business. Losses of wages to employees of a commercial establishment were considered when such losses were not compensated for by employment in emergency activities during the flood and rehabilitation period. Loss of salaries paid to owners of commercial establishments was normally included in the estimate of net profit loss of the business. Commercial flood fighting losses include those costs incurred in anticipation of and in fighting the flood.

Industrial damages include inundation losses to properties and facilities for extracting, producing, manufacturing and processing of commodities, wherein labor or materials create new products and new wealth. Business losses and flood fighting costs to industry are essentially the same as those listed in the paragraph above for commercial establishments, and vary principally in the economic magnitude of the goods and services involved.

Utility damages include inundation losses to all utilities, other than railroads, such as gas, electric, water and telephone plants, transmission lines and other similar facilities. Business losses to utilities include loss of sales or revenue, wages and increased costs of operation or substitute services. Flood fighting costs are also included in estimates of tangible utility damages.

Public damages include inundation losses to public buildings, parks and other facilities including equipment and furnishings owned or operated by Federal, state, county or local government units. Damages to church properties were included in this group. Public business losses include losses in sales or revenue, loss of wages, and increased cost of normal operations. Tangible public damages include flood fighting costs as previously defined.

Rural or agricultural damages include inundation losses to farm dwellings and furnishings, barns and other appurtenant buildings and their contents, including equipment, stored crops and feed, livestock

and poultry, land and crops, fences, lanes, bridges and other farm facilities. Rural business losses include loss in production or sales not covered under physical damages and increased cost of normal operation. Rural flood fighting costs are also a part of tangible damage estimates.

Highway damages include inundation losses to roads, streets, pavements, sidewalks, bridges and other highway structures, goods in transit or stored in terminals, supplies and equipment. Highway business losses include loss to the public caused by rerouting of traffic due to road or bridge damage plus other abnormal operating costs due to flooding. Again, flood fighting losses include costs incurred in anticipation of and in fighting the flood.

Railroad damages include inundation losses to tracks, structures, right-of-way, goods in transit or stored at terminals, supplies and equipment. Railroad business losses include loss of revenue due to reduced traffic and cost of substitute services due to flooding. Flood fighting losses similar to those previously discussed are included in estimates of tangible flood damages.

Emergency aid and relief includes the cost of protective and other work essential for the preservation of life and property, such as clearance of debris and wreckage, and emergency repair or temporary replacement of public facilities. Aid and relief activities include two general categories: (a) that furnished to the individuals and family units directly affected by a flood, and (b) that furnished for emergency rehabilitation of communities and cities rendered helpless by the flood. Aid to individuals and families is generally furnished by public and private social and welfare groups, and by the national disaster relief organizations. Assistance to communities and cities is largely the concern of state and Federal agencies whose functions include emergency aid and disaster operations.

22. Intangible Damages. Intangible damages are those losses that cannot be given a monetary value, such as loss of life, health, security and the detrimental effect of floods on national defense. If these losses were assigned values they would become tangible damages. Intangible damages were not used in project evaluation studies.

23. Damages to Fish and Wildlife Resources. It is recognized that floods may cause damages to fish and wildlife habitat. However, these types of damages do not lend readily to monetary evaluation as stated in the following paragraph furnished by the Department of the Interior, Fish and Wildlife Service.

"Habitat for fishes may be severely damaged as a result of the scouring effects of floods on aquatic food organisms and streambank cover. Erosion of stream margins and heavy deposition of silt are

also damaging to stream life. The impact of floods on other wildlife is somewhat less clear, although direct damages undoubtedly occur to wildlife species. On the other hand, the occurrence of floods on flood plain wildlife habitat discourages the development of cultural features which would encroach on that habitat." 3/

24. Recurring and Nonrecurring Damages. Recurring flood damages are those items of probable future damage which can be reduced or prevented by properly planned flood control measures. Nonrecurring flood damages are those items of previous loss which, although once experienced, are not likely to recur; for example, the destruction and nonreplacement of a bridge, or replacement in such a manner as to avoid or minimize future damage. Nonrecurring flood damages are not included in the tangible flood damage compilations utilized to determine average annual flood damages for the stream reaches.

25. Direct and Indirect Flood Damages. In the past it has been the general practice in the Corps of Engineers to classify flood damages as "direct and indirect." "Direct damages" are those damages caused by the flooding action itself, that is, the physical damage to property by inundation. "Indirect damages" are those damages other than physical, such as business losses, delays, flood fighting, and other adverse effects traceable to the flood. Flood damages previously reported as "direct" and "indirect" have been reclassified in accordance with EM 1120-2-112 as tangible damages under the following classifications: (1) physical losses, (2) business losses and flood fighting costs, and (3) emergency aid and relief costs.

26. PRIOR FLOOD INVESTIGATIONS AND REPORTS. Prior investigations pertaining to flood damages and flood control measures have been made under congressional authorizations. The River and Harbor Act of 21 January 1927 authorized eight investigations in the Delaware River basin under the provisions of House Document No. 308, Sixty-ninth Congress, 2d Session. The Emergency Relief Appropriation Act of 1935 authorized six flood control investigations and a stream pollution study in this area, and the Flood Control Acts passed between 1935 and 1946 authorized seven additional flood control investigations. In addition to those investigations authorized by Congressional Acts, resolutions adopted by various Congressional Committees have required the preparation of eight review reports. Additional information pertaining to these authorizations and investigations is given in Exhibit C, Prior Water Resources Report, of Appendix A, History of Investigation. The reports from which the earlier flood damage values originated are indicated in the notes to table 3.

3/ Letter dated 9 February 1960 from Regional Office, Fish and Wildlife Service, Boston, Mass., to the U. S. Army District Engineer, Philadelphia District.

27. Results of Prior Investigations. Flood damage estimates contained in prior reports for the Delaware River basin are summarized in table 3. Examination of the data shows that these damage surveys covered limited portions of the basin and that the results are only incidentally comparable with the total damages obtained by the basin-wide field survey following the August 1955 flood. The earlier damage surveys represent only a portion of the total damages that were experienced during the floods; that is, damage estimates were made only for areas of primary interest. However, data contained in the earlier reports were used to supplement the 1955 flood damage data. In such cases the earlier data were escalated for changes in price levels and increased by a factor indicative of normal growth and development.

28. SURVEY OF AUGUST 1955 FLOOD DAMAGE. The August 1955 storm produced the largest flood of record generally throughout the basin and provided an opportunity to secure data necessary to establish stage-damage relationships on a large number of streams not covered in earlier surveys. During and immediately following the 1955 flood, preliminary reconnaissance and aerial photographic surveys were made of the flooded areas in the basin. These were followed by a detailed field survey made during the period October through December 1955. In addition, a report was prepared by the U. S. Army Engineer District, Philadelphia, detailing Federal expenditures for emergency aid and relief measures performed during and after the flood of August 1955. A supplemental survey of the August 1955 flood losses was made in August 1958 for the purpose of securing additional flood damage data throughout the basin in order to define more adequately the stage-damage relations for various river reaches and damage centers. These surveys and reports are discussed in more detail in paragraphs 29 to 31 inclusive. Photographs, taken during and shortly after the flood of August 1955, are included in the back of this appendix. These photographs indicate, generally, the extent and magnitude of flooding and damages throughout the Delaware River basin.

29. Field Survey Immediately Following the Flood. In the survey conducted from October through December 1955 data were obtained, for the entire Delaware River basin, on flood damages resulting from the floods following hurricane "DIANE" on 18-20 August 1955. Subsequent to this flood, field survey teams interviewed owners of property, industrial, commercial and utility interests, public officials, and representatives of State and county highway departments and railroad lines which had experienced flood damage. Field data collected included estimates of tangible damages for the 1955 flood and also for stages three feet higher in the same flooded area. Although sampling techniques were used in some residential areas, the August 1955 flood damages were obtained principally from field interviews. Flood height marks were established and designated together with the extent of flooded areas on U. S. Geological Survey quadrangle sheets which are in the Philadelphia District Office files. A summary of the 1955

recurring and nonrecurring flood damages collected during this period are shown in tables 4 and 5.

30. Supplemental Damage Survey. A supplemental field survey made during August and September 1958 was used, primarily, to augment the 1955 flood damage data obtained in the earlier survey. Additional field data collected consisted of: (1) estimates of flood damages in areas not covered by the initial 1955 survey, (2) estimates of damage to structures constructed within the flooded area since the earlier survey, (3) estimates of reduction in recurring damages due to relocations and other protective measures, (4) damages that would have occurred for stages three feet higher than the 1955 flood in adjacent areas beyond the areas inundated by the 1955 flood, and (5) damages that would have occurred for stages six feet higher than the maximum stage of the 1955 flood on the Schuylkill River. Data from both flood damage surveys, including survey forms, maps of flooded areas, high watermarks and all other supporting data used to define flood damages in the Delaware River basin, are on file in the office of the U. S. Army Engineer District, Philadelphia.

31. Emergency Aid and Relief Survey. The relief furnished by the American Red Cross, costs of assistance to communities by the states and local agencies, and costs of emergency relief and rehabilitation performed by the Corps of Engineers are classified as emergency aid and relief costs. The emergency relief measures performed by the Corps of Engineers under Operation NOAH were initiated on 23 August 1955 by direction of the Federal Civil Defense Administration. These emergency relief activities were authorized under Public Law 875, 81st Congress, 2d Session, which provides for authorized Federal agencies to engage in disaster relief operations. The final report on Operation NOAH in the Delaware River basin, completed by the Philadelphia District on 31 January 1957, is a record of the activation, mobilization, administration, expenditures, and the general location of disaster relief operations. The American Red Cross and Operation NOAH costs were generally reported as lump sum amounts for political subdivisions such as states, counties, townships and metropolitan areas. Essentially all of the emergency work performed through contract services under the direction of the Corps of Engineers was completed by 30 July 1956. Disaster and relief work on state, county or local levels, with costs reimbursable by the Federal government, was completed by 10 December 1956.

32. EVALUATIONS OF 1955 FLOOD DAMAGES. The damage reports, sorted into appropriate damage centers, local township areas, river reaches, watersheds, and by types of property damage, were reviewed for errors, omissions or duplications. Corrections were made, and additional information was secured in the field when necessary. Utility, railroad, highway, and emergency aid and relief damages reported as lump sum estimates for large political subregions were prorated to

the damage centers and reaches as indicated in paragraph 33. Damage estimates were made for business losses and emergency costs based on methods discussed in paragraph 34. Changes in dollar values were considered, and the escalation factors developed for adjusting the 1955 damage estimates to 1958 and 1959 values are shown in paragraph 35. The procedures discussed in paragraphs 33 to 35 inclusive were used to develop damage estimates for the flood of 1955 and for the hypothetical flood three and six feet higher. Table 6 illustrates the calculation of total recurring flood damage for typical damage reach.

33. Distribution of "Lump Sum" Damage Estimates. Flood damage estimates for large utilities, state and county highways, railroad companies, and emergency aid and relief measures were reported as lump sum expenditures for large areas such as states, counties, metropolitan areas, and service areas. It was first necessary to prorate the lump sum estimates among the damage centers and reaches on an equitable and consistent basis. The lump sum damage estimates for utilities, highways, and railroads were prorated on the basis of inundated miles of roads, tracks and service lines indicated within each damage reach by high water profiles and flooded area maps. Corps of Engineers' emergency expenditures for specific damage centers, along with other supporting data from the report on Operation NOAH, were used to prorate the reimbursable state, county, and local agency lump sum emergency aid expenditures. Red Cross expenditures reported as lump sums were prorated to individual damage centers and damage reaches in proportion to the amount of included residential damages.

34. Business Loss and Emergency Cost Adjustments. Business losses and flood fighting costs as well as Red Cross expenditures resulting from the August 1955 flood were reported in the original survey for class, or type, of damage and classified as "indirect" flood damage. Railroad, highway, and utility business losses and emergency costs were generally reported as lump sum estimates for large areas, while residential, commercial, industrial and public losses were reported for individual properties. In no case were these losses obtained in the original survey for a flood three feet higher than that of 1955. To account for all losses of this type, percentage relationships of business loss and emergency cost to actual physical damage were developed from the 1955 flood damage data obtained in the Delaware and adjacent watersheds. These relationships, obtained from the New York, Baltimore, Washington and Philadelphia Districts of the Corps of Engineers, together with similar information computed for commercial and industrial damages based on the supplemental damage survey, are shown in table 7. Based on these relationships, percentages were adopted for estimating business losses and emergency costs, including Red Cross, for each class of flood damage as indicated in table 7. The adopted percentages were used to compute the business losses and emergency costs for the 1955 flood as well as a flood three feet higher. This resulted in more consistent relations of business

losses and emergency costs for the two floods than were obtained using the surveyed "indirect" damages for the 1955 flood and adopted percentages for the 1955 flood height plus three feet. The 1955 flood damage loss in the basin is not significantly altered by using the percentage method of deriving business losses and emergency costs.

35. Escalation of Flood Damage Values. The June 1958 price level was used as the common basis for the integration of all flood damages used in preliminary planning studies. The flood damages surveyed in 1955 were escalated to 1958 price levels and incorporated with damage data collected in the supplemental survey of 1958. The Building Cost Index, published in the "Engineering News-Record" and the Consumer Price Index (all items), published in the "Monthly Labor Review," were used to develop the average escalation factor, 1.085, which was used to escalate 1955 flood damage values to 1958 values. In order to compare annual damages prevented and annual project costs, which are based on January 1959 prices, it was necessary to escalate the recurring flood damage estimates to 1959 price levels. The average escalation factor for increasing 1958 to 1959 price levels is given in the following tabulation.

ESCALATION FACTORS FOR CONVERTING PRICE LEVELS

Source of Information	Index Aug 1955	Index June 1958	Index Jan 1959	Ratio 1958/1955	Ratio 1959/1958
Building Cost Index	478.03	521.09	536.23	1.0901	1.0290
Consumer Price Index (all items)	114.50	123.70	123.80	1.0803	1.0008
Factor-Average Ratio	-	-	-	1.085	1.015

The difference between the B.C.I. and the C.P.I. is reflected in the year selected for each as a base from which price levels are measured. The base for the B.C.I. is 1913 and for the C.P.I. it is 1947-49.

36. DISTRIBUTION OF DAMAGES BELOW 1955 FLOOD CREST. Detailed stage-damage data from prior studies were limited to the Lackawaxen and Lehigh Rivers and a few isolated damage centers. Stage-damage curves developed by the office of the U. S. Army Engineer District, Philadelphia, in these areas were used where possible in this report. Damages for specific floods prior to 1955 on the Schuylkill River, together with flood damages for the August 1955 flood, the 1955 flood plus three feet, and the 1955 flood plus six feet were sufficient to define stage-damage curves for the various reaches used on this stream. For the main stem of the Delaware River and the remainder of the tributaries, recurring flood damages below the 1955 flood stage

were distributed vertically according to empirical relationships of depth of flood versus percentage of total flood damages. Vertical distribution of damages between the 1955 stage and the 1955 stage plus three feet, or above the 1955 stage plus three feet, was not necessary as these two flood damage values adequately defined the upper portion of the stage-damage curves.

37. The relationships for distribution of damages below the 1955 stage for various classes of damages are discussed in paragraphs 38 to 43 inclusive. These relationships were tested by application to the May 1942 flood damages on the Lehigh River and to the flood damages for the 1955 stage plus three feet on the Schuylkill River. The derived damage distributions at stages below these flood crests were then compared with the established stage-damage curves for the reaches tested. These tests showed that the summation of individual damage distributions based on the empirical relationships gave stage versus total damage curves which compared favorably with the existing curves for the reaches.

38. Residential Damages. Generalized residential damage tables had been developed by the U. S. Army Engineer District, Baltimore, in connection with flood damage studies on the Susquehanna River. The tables gave the relationship of physical damages to depth of inundation by type and class of residence. Since the Susquehanna and the Delaware River basins are in a similar economic region, and the same general type of residences are found in both flood plains, these tables were used as a basis for distributing residential damages in the Delaware River basin. For this study, new tables were prepared based on percentages instead of dollar values. These tables give, in terms of percentages of total damages at known maximum depths of flooding, the damages for each successive foot of lesser inundation for one and two story residences, both with and without basements. The percentages were applied to the total physical damage to each residence caused by the August 1955 flood and the dollar damage for each foot of depth below the flood crest computed. Damage values for each residence for the 1955 depth of inundation and for each lesser foot below the 1955 depth were summed up by reaches and damage centers, and were later combined with other classes of flood damages to give the depth-damage distributions. In the procedure used, and described above, it is assumed that in any reach flood profiles at various stages above the zero-damage stage for the reach are parallel. This assumption is substantiated by flood profiles of record for the Delaware River and principal tributaries.

39. Commercial and Industrial Damages. Damages at stages between the 1955 crest and the zero-damage stage for each property were determined in accordance with a linear type distribution. For example, the flood damage for a commercial establishment, flooded to a depth of five feet above zero damage in 1955, is reduced 1/5 or 20

percent per foot of lesser depth of inundation below the crest. Tabulations were prepared showing the distribution of damages per foot of inundation for each individual commercial and industrial establishment and summarized by reaches and damage centers.

40. Highway, Utility, Public and Rural Damages. In general, the depth of flooding was not indicated on the survey data forms for these types of damages, and in some cases the 1955 damages were listed only by broad areas or systems. Since the physical damages in this group are somewhat similar to those occurring in residential, commercial, and industrial classes, the generalized relations used for these categories were used as a basis for distribution of the damages for this entire group. Summaries were prepared of the total residential, commercial, and industrial physical damages in each of the individual reaches and damage centers under consideration. Percentage distributions of these combined damages per foot of depth of inundation were calculated for each of the reaches. These percentages were then applied to the total of the highway, utility, public and rural damages for each reach and damage center to obtain damage distributions in feet below the 1955 flood crest.

41. Railroad Damages. The damage data forms from the field survey listed railway damage along the Delaware River for Reaches A, B, and C in August 1955. Examination of available profiles and maps showing railroad locations indicated that the average depth of flooding was about five feet in Reaches A and B and greater than that in Reach C. Railway physical damages in Reaches A and B were distributed vertically within the five-foot depth on a linear basis. Railway damages in Reach C were distributed vertically on the same basis as highway damage in Reach C. Railroad damage data for most of the tributary areas were listed as lump sums which were prorated to the appropriate damage centers and reaches on the basis of field data, personal knowledge acquired by field investigators and judgment. Approximately the same distribution by feet below the crest of the 1955 flood was applied as along the Delaware River.

42. Business Losses and Costs of Emergency Measures. These losses were determined for each class of property as discussed in paragraph 34. The percentage values determined from the residential, commercial and industrial physical damage distributions, and previously used for distributing highway, utility, public and rural physical damages by feet below the 1955 flood crest, were used to distribute all business losses and costs of emergency measures except railroad loss. The percentages used for vertical distribution of railroad losses were the same as those used for railroad physical damage.

43. Federal Emergency Expenditures. Expenditures of this type, as listed in the report on Operation NOAH for the 1955 flood, were distributed vertically by the same percentages as those used above for

business losses and costs of emergency measures. The values obtained were then inserted in the appropriate vertical distribution summaries.

44. Summation of Distributed Damages. All of the recurring damages (physical, business and emergency losses) for each of the various classes were determined and summarized for the August 1955 flood stage and each foot of lesser inundation below this flood crest for each reach and selected damage center. From these summaries stage-damage curves were prepared in which stage was referenced to feet below the 1955 flood crest. The stage was then converted to elevation in feet above mean sea level or gage height by referring the 1955 flood crest to a nearby reference point or stream gage.

45. DETERMINATION OF AVERAGE ANNUAL DAMAGES. Stage-damage, stage-discharge, and discharge-frequency relations were developed independently for the various reaches and damage centers throughout the Delaware River basin. These relations were correlated to develop damage-frequency curves which were used in the determination of average annual recurring flood damages.

46. Stage-Damage Relations. The procedures outlined in paragraphs 34 to 44 inclusive, gave damage data for various flood stages in each of the reaches or damage centers under study. In most cases, the stage-damage relations were developed from the flood data for the August 1955 flood, the anticipated damages from a flood of the 1955 stage plus three feet and, on the Schuylkill River, the damages anticipated from the 1955 stage plus six feet. The stages corresponding to zero damage were determined from information secured during the course of the original and supplemental damage surveys. Plate 3 shows a typical stage-damage curve for Reach C-1 on the Delaware River.

47. Stage-Discharge Relations. Most of the damage reaches and centers were so located that it was possible to use existing U. S. Geological Survey stream gaging stations as reference gages. In the few reaches where existing gages were not applicable, peak discharges for reference points were derived for the floods of 1936, 1942, 1952 and 1955 based on the recorded discharges at nearby gages. These recorded discharges together with flood profiles and/or high watermarks were used in developing rating curves at the reference points. Plate 4 shows a rating curve for the Delaware River at Belvidere, New Jersey, which was used for Reach C-1.

48. Discharge-Frequency Relations. General data on the development of discharge-frequency relations for the Delaware River basin including procedures for the determination of regionalized frequency curves at reference points other than established gaging stations are presented in paragraphs 68 to 88, inclusive, of Appendix M. A comparison of frequency curves developed by regionalized methods with statistical frequency curves determined from the station records,

generally throughout the basin, showed that the former did not diverge materially from the statistical curves. Accordingly, and in the interest of uniformity for the gaged and ungaged damage index stations, the regionalized frequencies were used for all damage-frequency relations. Spot checks showed that the use of regionalized frequencies in lieu of statistical frequencies based on reasonably adequate observed data made insignificant changes in the estimates of annual damages except in the case of Brandywine Creek at Chadds Ford, Pennsylvania where the actual frequency curve, based on 44 years of stream flow record, was used. Plate 5 shows a regionalized discharge-frequency curve for natural conditions and modifications for the effect of existing reservoirs and reservoir projects under construction for the damage Reach C-1. Modification of natural flood frequency curves for the effect of existing reservoirs and reservoir projects under construction is described in paragraphs 90 and 91 of Appendix M.

49. Damage-Frequency Curves. Damage-frequency curves were developed by the correlation of stage-damage, stage-discharge, and discharge-frequency relations for each damage reach or center. As a typical example, plate 6 shows these relations for damage Reach C-1 plotted as curves in separate but related quadrants. The damage-frequency curve constructed therefrom is shown in the lower right quadrant. Plotting points for this curve are derived by converting the stage corresponding to a selected damage value into discharge, and then converting this discharge into its associated frequency which is plotted against damage. Normally these four curves are constructed on separate sheets with larger scales in order to provide a more accurate definition of the damage-frequency curve. Enlarged damage-frequency curves for Reach C-1 under natural conditions and for conditions modified by existing reservoirs and reservoir projects under construction are shown on plate 7. The total area under the damage-frequency curve is in effect the summation of the average annual damage expected at each frequency and represents the total average annual damages. The average annual recurring damages thus obtained are summarized in table 8 for natural conditions and for resulting conditions after modification by existing reservoirs and reservoir and local protection projects under construction where applicable. The average annual recurring damages in this table are for those reaches of the Delaware River and tributary streams where detailed evaluations were needed to fully develop flood control measures in connection with the comprehensive plan for water resource development in the basin.

50. TRENDS OF DEVELOPMENT. Studies were undertaken to modify the current average annual flood damage estimates to reflect the increased potential average annual flood damages throughout the 50-year life of the proposed projects. This was accomplished through estimation of the expected "normal" trend of flood plain development in those areas for which damage reduction measures are being proposed. The study was undertaken in recognition of the fact that by the year

2010 continued "without-project" flood plain development could significantly modify the current picture of damage potential. The following paragraphs present an analysis of the Delaware River basin's historic flood plain development, the methods explored to estimate future trends of flood plain development, a detailed description of the adopted method, and the results of the application of the adopted method in the measurement of the basin's probable flood plain growth.

51. For the purposes of this phase of the study, the following three major river reaches were selected because of the significant damages suffered in these areas in the 1955 flood:

Delaware River Reach:	Riegelsville, Pennsylvania to Trenton, New Jersey, inclusive
Lehigh River Reach:	Bowmanstown, Pennsylvania to Easton, Pennsylvania, inclusive
Schuylkill River Reach:	Reading, Pennsylvania to Norristown, Pennsylvania, inclusive.

The physical characteristics of the flood plains in these reaches are discussed in paragraphs 3, 9 and 10, respectively. Despite the relative narrowness of the flood plain, there exists a high degree of physical development, attested by the magnitude of the August 1955 flood damages as shown in table 4. Of the total damages in the Delaware River basin for the 1955 flood, 50 percent occurred in the combined area covered by the above river reaches.

52. While the relatively narrow valley widths and the high degree of present development indicate only minimal future flood plain development, the pressure of social and economic factors, already exerting their influence in the Delaware River basin, may serve as forces which will accelerate a more intensive use and redevelopment of the flood plain in the future. The emphasis on urban redevelopment coupled with trends of population growth will result in new development along the flood plain. An example of this is at Trenton, New Jersey, where a multimillion dollar housing development is presently contemplated on a flood plain area now occupied by older, less valuable structures.

53. A number of geographic and social factors may be related to flood plain development. A recent study completed by the Department of Geography at the University of Chicago 4/ indicates that a relationship exists between flood plain occupancy and general population

4/ Changes in Urban Occupancy of Flood Plains in the United States, Gilbert White, Wesley Calef, et al., University of Chicago, Department of Geography, Research Paper No. 57, November 1958.

growth. Another factor that may influence future trends in flood plain development is the Federal highway program. In New Jersey alone three Federally supported interstate highways are proposed which will pass through flood plain areas at Trenton, Phillipsburg and Columbia. Additional forces that may also influence future development and potential flood damages are such factors as flood plain zoning, introduction of new building standards designed to minimize flood damages, flood insurance, and improved forecasting and flood warning systems.

54. Methods for Evaluating Trends of Development. Recognizing the nature of the limiting parameters to flood plain development, as well as the effects of various factors mentioned above, several methods of measuring future trends of flood plain development were investigated. Among the various avenues of approach that could be explored for estimating development trends, the three following bases were considered to be within the practical limits of report objectives:

a. Historical and projected overall economic growth.
b. Actual flood plain development determined by field survey.
c. Measurement of changing patterns of land use in the flood plain.

55. Historical and Projected Overall Economic Growth. The first method involved an analysis of the historical and projected trends of overall economic growth based on changes in population and personal income for each problem area. The Office of Business Economics, in the Economic Base Survey, Appendix B, provided adequate historical and projected growth data for the Delaware River service area and its eight subregions. These data could be used to measure future trends of flood plain development for flood problem areas distributed by counties. However, while the overall growth patterns developed for a county or a group of counties, covering the river reach under study, would be valid for the general locality, there were no methods readily available for determining if such trends would also be applicable for the specific portion of the county or counties lying within actual flood plains. Field reconnaissance studies were undertaken in the Allentown-Bethlehem-Easton, Pennsylvania and Trenton, New Jersey areas in order to determine the feasibility of this method. In the Allentown-Bethlehem-Easton area it was ascertained that over a 20-year period there had been little flood plain development in Easton and only moderate increases were recorded for Bethlehem and Allentown. During a similar period population for the general area was increasing at a rate of approximately one percent per year. At Trenton, very significant increases in flood plain development have been noted during the last 20 to 25 years and population growth within this metropolitan area has averaged about 1-1/2 percent. These studies did not indicate that there existed any measurable relationship between population growth and flood plain development for the sample areas studied.

56. Flood Plain Development Determined by Field Survey. The second method under consideration would involve making the following studies: (a) sample field surveys within each reach under study to explore all available records relating to flood plain development such as building permits, tax rolls, city directories, channel encroachment permits, etc.; (b) supplementary interviews with local officials and citizens to obtain any future plans for development within the flood plain; and (c) a detailed study of the sample area in order to determine the amount of land available for future development and what normal changes in land use might be expected. In contrast to the first method, this procedure concentrates entirely on changes within the flood plain proper with field survey data secured from the sample areas within each reach translated into growth factors and applied to each individual river reach. Several problems inherent in the use of this method precluded its adoption for the determination of trends of development. For example, in the reconnaissance survey made in connection with the first method it was found that not all cities, townships or boroughs kept consistent records from which the pattern of historical flood plain development could be derived. For some areas such records were found to be nonexistent.

57. Measurement of Changing Patterns of Land Use. The approach using the changes in land use from nonurban to urban during a specific time period as a measure of historical development within a flood plain area was adopted for use in the final determination of future trends of development in the Delaware River basin. The method of interpreting aerial photographs for appraising various land uses was developed by the Soil Conservation Service 5/ in connection with the New England-New York Inter-Agency Committee's study of the effect of flood control dams on land value enhancement. A detailed description of the application of this method is given in the subsequent paragraph.

58. Aerial photographs obtained from the Commodity Stabilization Service, U. S. Department of Agriculture, provided coverage of the three river reaches described in paragraph 51. A set of aerial photographic mosaics for the years 1938 and 1958 was utilized for the Delaware and Lehigh Rivers. The earliest set of aerial photographic mosaics available for the Schuylkill River was for the year 1942. The flood plain subject to the 1955 flood was delineated on the mosaics for the Lehigh River from maps of flooded area and stream profiles. Due to the relative narrowness of the flood plains on the Schuylkill and Delaware Rivers, described in paragraphs 2 to 13 inclusive, and the scale of the photographic mosaics, the delineation of the flood plain proper on the mosaics for these two river reaches did not embrace areas of sufficient magnitude to permit interpretation. By

5/ Henry W. Dill, Jr. - "Photo Interpretation of Flood Control Appraisal," Photogrammetric Engineering, March 1955.

widening the area delineated on these mosaics to a width of not more than 1/2 mile from the center line of each river reach to include not only the flood plain area, but also areas immediately adjacent to it, it was possible to undertake a meaningful aerial photograph analysis for the Delaware and Schuylkill Rivers. While the wider area in some instances included portions of land outside of the flood plain, no adjustment was necessary in the overall land use pattern to reflect growth on the flood plain itself. In those adjacent areas included within the analysis of land use changes, it was assumed that growth had been generally similar to that on the flood plain proper. Preliminary aerial photographic map studies revealed that several broad land use classes could easily be identified, and further, that these classes were sufficiently inclusive to be used as a basis for measuring the historical development. The classes are as follows:

a. Urban areas including residential, commercial, industrial, and public development.

b. Nonurban areas including crop and pasturelands, forest lands, brush and open undeveloped areas.

c. Transportation areas occupied by railroad facilities, highways, bridges and canals.

Land use in the flood plain and adjacent areas in a river reach for a given year was determined by dot count using a transparent dot grid superimposed on the delineated area of the aerial mosaic. For each river reach the total number of dots falling within the boundary of the delineated area was counted. The dot count was then segregated on the basis of the type of land use directly under each dot. Based on tested sampling techniques, employing the use of the dotted grid, it was possible to determine the historical land use pattern within a delineated area. For instance, on the Lehigh River in 1939 it was found that about 50 percent of the total flood plain delineated was under urban and transportation development. By 1958, more than 54 percent of the flood plain studied was developed for urban and transportation use, relative increase of about 8 percent. Historical land use patterns for each of the river reaches for each pair of years investigated are shown in the following tabulation.

LAND USE PATTERN - LEHIGH, SCHUYLKILL
AND DELAWARE RIVER FLOOD PLAINS
(as percent of flood plain and adjacent area)

Lehigh River	1939	1958
Flood plain, total	100.0	100.0
Nonurban	50.0	45.7
Urban	26.0	27.6
Transportation	24.0	26.7
Schuylkill River	**1942**	**1958**
Flood plain & adjacent, total	100.0	100.0
Nonurban	57.1	48.7
Urban	18.5	23.0
Transportation	24.4	28.3
Delaware River	**1938**	**1958**
Flood plain & adjacent, total	100.0	100.0
Nonurban	68.0	63.5
Urban	14.6	18.6
Transportation	17.4	17.9

59. Projections of Trends of Development. Projections of future trends of development in the flood plain and adjacent areas for each of the three river reaches were obtained by a straight line extrapolation of the historical pattern of development described in the previous paragraph. Adoption of straight line projections was governed by consideration of the overall economic growth of the areas in and around the flood plain and the physical potential of the flood plain to sustain additional urban and transportation development over the next fifty years. Consideration was given first to the historical and projected pattern of economic activity within those broad areas through which these three river reaches flow. These are the Allentown-Bethlehem-Reading and the Philadelphia Metropolitan Areas. In the former area the population is expected to increase over the next fifty years at an average annual rate of more than 2-1/2 times the annual rate evident over the last 25 years. In the Philadelphia Metropolitan Area the projected population growth rate is expected to exceed by close to two times the historical population growth rate experienced between 1930 and 1955. In 1955 about 6 percent of the total land area of the Bethlehem-Allentown-Reading subregion and 18 percent of the land area of the Philadelphia Metropolitan subregion were in urban development. By 2010 more than 20 percent of the total land area will be in urban use and nearly 65 percent of all land in the Philadelphia Metropolitan Area will be utilized for urban purposes,

greater than a threefold increase in each area. These estimates were developed from data contained in Appendix G - Irrigation and Rural Water Use, prepared by the U. S. Department of Agriculture. While the above factors seem to indicate that urban development on the flood plain should grow at a rate somewhat in excess of its historical pattern of growth, consideration given to the physical limits and present utilization of the flood plain reveal that accelerated growth is not warranted. As shown in the tabulation of land use patterns, about half of the flood plain and adjacent areas studied are currently in urban and transportation development. Substantial modification of past flood plain growth to reflect the population and land use changes projected for the broad metropolitan areas discussed above would conceivably exhaust the flood plain's potential for new urban development well before 2010. The narrowness of the flood plain in presently nonurban areas as well as the existence of major transportation facilities extending throughout broad reaches of the flood plain in both urban and nonurban areas prohibits major land use changes over the next fifty years such as those indicated for the two broad metropolitan areas. The impact of measures to limit further flood plain development, such as flood plain zoning, although unprojectable in the future, were also taken into account as factors mitigating against the use of increased growth rates to measure future trends of development.

60. In light of these considerations, it was felt that a projection of future trends of flood plain development for these three river reaches could best be estimated by a continuation of the past growth into the next fifty years. Employing a straight line extrapolation of past growth, it is expected that urban flood plain development in the Lehigh River will increase from 54 percent in 1958 to 66 percent by 2010. On the Schuylkill River, urban growth on the flood plain and adjacent area will grow from 51 percent in 1958 to 79 percent by 2010. For the Delaware River, urban flood plain growth will increase from 37 percent in 1958 to 48 percent by 2010. Projections of future trends of flood plain development in terms of equivalent average level of development in 1958 are shown below for the years 1980 and 2010.

	1958	1980	2010
Lehigh River	100	109	122
Schuylkill River	100	123	154
Delaware River	100	113	132

61. Application of Trends of Development to Average Annual Damages. Average annual damages on the Lehigh River, Schuylkill River and Delaware River and their respective tributaries were increased by the trend of development growth factors to reflect the potential damages in years 1980 and 2010. It was assumed that new developments on the flood plain in these years would be subject to flood hazards similar to those reflected by the average annual damages computed for 1958

levels of development. With respect to stage, future or additional developments would, on the average, be distributed in the same proportion as the 1958 development. The trends of development used herein are considerably lower than the trends projected for the overall urban development of the basin. It is therefore considered that sufficient weight has been given to the ameliorating effects of flood damage reduction measures (such as zoning, flood warning and design criteria which would tend to make buildings less susceptible to flood damage) in applying the trend of development factors directly to the average annual flood damages. If such measures were not considered, it would have been necessary to use a modified trend factor to apply to the average annual damage estimates. Prospective average annual damages for the three river reaches in terms of 1980 and 2010 levels of physical development are shown below at the January 1959 price level.

	1958	1980	2010
Lehigh River and Tributaries	$1,183,800	$1,290,300	$1,444,200
Schuylkill River and Tributaries	1,349,500	1,659,900	2,078,200
Delaware River and Tributaries	3,420,600	3,865,300	4,515,200

62. SUMMARY. Estimated values of recurring and nonrecurring flood damages throughout the Delaware River basin secured from the field survey following the 18-20 August 1955 flood totaled $104,716,000. These values were increased to reflect the level of development in August 1958 by (a) the addition of new structures within the flooded area constructed since the survey, and (b) the escalation of 1955 prices to 1958 levels. These revised flood damage values for the entire basin amounted to $123,500,000, and the recurring flood damages in all reaches and damage centers investigated in this study amounted to approximately $86,725,200 or 70 percent of the basin total. A portion of the 30 percent not included in this total is attributable to the elimination of nonrecurring damages and the remainder are damages in the headwater reaches of the streams. These latter damages are considered in studies pertaining to the feasibility of upstream reservoirs reported in Appendix R. The average annual damages, for the 1958 level of development, were $9,223,900 based on the January 1959 price level. Existing flood control measures and flood control projects under construction will eliminate $3,126,000 of these damages, resulting in a net average annual damage of $6,097,900. The net average value of annual damages, modified by the effects of proposed flood control structures with adjustment for future trends of development, is used as a basis for the determination of final flood control benefits. These modifications are described in Appendix V.

TABLE 1

MAJOR DAMAGE CENTERS - DELAWARE RIVER BASIN
DIMENSIONS AND CHARACTERISTICS OF INUNDATED AREAS

Damage Centers	Stream	Flood	Flooded Area			No. of Properties Inundated		
			Average Width, ft.	Length ft.	Area ac.	Residen- tial	Commer- cial	Indus- trial
Margaretville, N.Y.	E.Branch Delaware R.	Nov 1950	700	6,300	100	100	30	0
Rockland, N.Y.	Beaverkill	Nov 1950	500	3,500	40	30	0	0
Roscoe, N.Y.	Willowemoc Cr.	Nov 1950	600	4,500	65	12	17	3
Livingston Manor, N.Y.	L.Beaverkill & Willowemoc Cr.	Nov 1950	500	3,500	40	69	30	1
South Fallsburg, N.Y.	Pleasure Lake	Aug 1955	700	2,500	40	14	5	0
Monticello, N.Y.	Tannery Brook	Aug 1955	350	1,850	15	84	31	0
Honesdale, Pa.	Lackawaxen R. and Dyberry Cr.	May 1942	1,200	9,000	250	644	180	25
Hawley, Pa.	Lackawaxen R. and Middle Cr.	May 1942	860	5,000	100	60	11	4
South Sterling, Pa.	Wallenpaupack Cr.	Aug 1955	200	2,000	10	10	5	0
Newfoundland, Pa.	Wallenpaupack Cr.	Aug 1955	700	3,000	50	30	41	0
Greentown, Pa.	Wallenpaupack Cr.	Aug 1955	300	1,500	10	12	2	0
Port Jervis, N.Y.	Delaware R. and Neversink R.	Aug 1955	240	9,000	50	494	69	6
Matamoras, Pa.	Delaware R. (Reach A-2b)	Aug 1955	2,700	4,000	250	70	6	0
Belvidere, N.J.	Delaware R. and Pequest R.	Aug 1955	500	4,500	50	58	20	0
Easton, Pa.	Delaware R.& Lehigh R.	Aug 1955	500	23,000	265	237	119	12
Phillipsburg, N.J.	Delaware R.(Reach C-2a)	Aug 1955	500	16,000	180	32	17	3
Riegelsville, Pa.	Delaware R.(Reach C-2b)	Aug 1955	1,000	4,400	100	134	25	1
New Hope, Pa.	Delaware R.(Reach D)	Aug 1955	600	5,600	80	146	0	0
Yardley, Pa.	Delaware R.(Reach D)	Aug 1955	1,100	6,000	150	223	26	0
Trenton, N.J.	Delaware R.(Reach D)	Aug 1955	500	21,500	250	358	46	9
Burlington, N.J.	Delaware R.(Reach E)	Aug 1955	2,100	12,000	580	875	77	4
Canadensis, Pa.	Brodhead Cr.	Aug 1955	450	4,000	40	31	21	0
Tannersville, Pa.	Pocono Cr.	Aug 1955	700	1,200	20	52	18	0
East Stroudsburg, Pa.	Brodhead Cr.	Aug 1955	1,200	10,000	275	308	29	0

TABLE 1 - Continued
MAJOR DAMAGE CENTERS - DELAWARE RIVER BASIN
DIMENSIONS AND CHARACTERISTICS OF INUNDATED AREAS

Damage Center	Stream	Flood	Flooded Area			No.of Properties Inundated		
			Average Width,ft.	Length ft.	Area ac.	Residen-tial	Commer-cial	Indus-trial
Stroudsburg, Pa.	Brodhead Cr. & Pocono Cr.	Aug 1955	1,000	8,500	195	321	55	9
Newton, N. J.	Paulins Kill	Aug 1955	350	2,500	20	10	14	0
Blairstown, N. J.	Paulins Kill	Aug 1955	650	4,600	70	48	41	0
Lehighton, Pa.	Lehigh R.(above Reach 5)	Aug 1955	650	2,300	35	0	1	0
Weissport, Pa.	Lehigh R.(above Reach 5)	Aug 1955	700	3,600	60	103	7	3
Bowmanstown, Pa.	Lehigh R. (Reach 5)	Aug 1955	600	1,100	15	0	0	2
Palmerton, Pa.	Lehigh R. (Reach 5)	Aug 1955	80	6,000	10	0	0	2
Slatington, Pa.	Lehigh R. (Reach 5)	Aug 1955	200	700	3	1	3	2
Walnutport, Pa.	Lehigh R. (Reach 5)	Aug 1955	150	1,500	5	2	1	1
Treichlers, Pa.	Lehigh R. (Reach 5)	Aug 1955	200	1,200	5	5	1	1
Catasauqua, Pa.	Lehigh R. (Reach 4)	Aug 1955	170	6,250	25	2	2	0
Allentown, Pa.	Lehigh R., Jordan Cr. & Little Lehigh R.	Aug 1955	1,000	16,500	380	155	48	21
Bethlehem, Pa.	Lehigh R.& Monocacy Cr.	Aug 1955	900	23,000	480	78	34	12
Freemansburg, Pa.	Lehigh R. (Reach 3)	Aug 1955	460	5,700	60	71	8	1
Bath, Pa.	Monocacy Cr.	Jul 1945	220	3,100	15	28	8	3
Chalfont, Pa.	Neshaminy Cr.	Aug 1955	450	5,400	55	15	6	1
Newportville, Pa.	Neshaminy Cr.	Aug 1955	800	3,200	60	112	0	0
Tamaqua, Pa.	L.Schuylkill R. & Wabash Cr.	Aug 1955	1,350	3,100	95	233	45	2
Kutztown, Pa.	Sacony Cr.	May 1942	750	10,000	175	25	5	5
Reading, Pa.	Schuylkill R. (Reach 6)	Aug 1955	670	8,500	130	273	10	6
Birdsboro, Pa.	Schuylkill R. (Reach 5)	Aug 1955	450	1,000	10	57	5	0
Pottstown, Pa.	Schuylkill R. (Reach 5)	Aug 1955	550	20,000	250	258	14	3
Norristown, Pa.	Schuylkill R. (Reach 4b)	Aug 1955	150	12,000	40	3	4	7
Norristown, Pa.	Stony Creek	Aug 1955	500	7,600	85	0	6	1
Norristown, Pa.	Saw Mill Run	Aug 1955	400	7,800	70	15	29	0
Downingtown, Pa.	E.Br.Brandywine Cr.	Aug 1955	500	7,000	80	152	0	3
Coatesville, Pa.	W.Br.Brandywine Cr.	Aug 1955	650	6,000	90	0	0	1

TABLE 2

DELAWARE RIVER FLOOD PLAIN DIMENSIONS AND CHARACTERISTICS

	Port Jervis to Wallpack Bend	Wallpack Bend to Tocks Island	Tocks Island to Belvidere	Belvidere to Riegelsville	Riegelsville to Lumberville	Lumberville to Trenton
Flood Plain Dimensions						
Length of Reach (miles)	29	19	20	23	19	21
Area flooded Aug. 1955						
River (Acres)	1,787	452	1,518	1,403	1,566	1,988
Overbank (Acres)	4,045	901	1,975	1,548	2,350	3,350
Total Area (Acres)	5,832	1,353	3,493	2,951	3,916	5,338
Width flooded August 1955						
River (Feet)	400	200	460	450	800	1,000
Plain (Feet)	1,250	390	980	610	900	1,100
Total Width (Feet)	1,650	590	1,440	1,060	1,700	2,100
Flood Plain Characteristics						
Area Flooded in 1955						
Urban (Acres)	3	0	422	505	428	1,172
Agricultural (Acres)	2,146	508	650	161	884	828
Woodland (Acres)	1,722	371	618	382	672	796
Transportation (Acres)	174	22	285	500	366	554
River (Acres)	1,787	452	1,518	1,403	1,566	1,988
Total (Acres)	5,832	1,353	3,493	2,951	3,916	5,338

TABLE 3
FLOOD DAMAGE ESTIMATE IN PRIOR REPORTS
DELAWARE RIVER BASIN

(All values in thousands of dollars, per date of flood occurrence)

Damage Location	14 Dec 1901	28 Feb 1902	10 Oct 1903	8 Mar 1904	26 Aug 1928	6 Oct 1932	28 Aug 1933	7-10 Jul 1935	12-18 Mar 1936	22 Sep 1938	4 Mar 1939	21 Au 1939
	DATE OF FLOOD											
Delaware River	-	-	-	-	-	-	-	-	-	-	-	-
East Branch	-	-	-	-	71.4 2/	163.5 2/	17.9 2/	13.4 2/	141.0 2/	-	-	-
West Branch	-	-	-	-	-	-	-	990.3 2/	40.5 2/	-	-	-
Hancock to Port Jervis	-	-	-	-	-	-	-	2.5 2/	60.4 2/	-	-	-
Port Jervis - Easton	-	-	-	-	-	-	-	-	594.7 2/	-	-	-
Easton to Trenton	-	121.4 1/	-	-	-	-	-	-	772.9 2/	-	-	-
Trenton - Philadelphia	-	-	-	-	-	-	-	-	50.0 2/	-	-	-
Port Jervis	-	-	300.0 1/	-	-	-	-	-	-	-	-	-
Trenton	-	-	31.0 3/	20.0 3/	-	-	-	-	22.3 4/** 83.0 3/	-	-	-
Morrisville	-	-	-	-	-	-	-	-	72.5 3/	-	-	-
Lackawaxen River	-	-	-	-	-	-	-	-	688.8 2/*	-	-	-
Prompton	-	-	-	-	-	-	-	-	-	-	-	-
Seelyville	-	-	-	-	-	-	-	-	-	-	-	-
Honesdale	-	-	-	-	-	-	-	-	211.7 4/**	2.6 4/**	-	-
White Mills	-	-	-	-	-	-	-	-	-	-	-	-
Hawley	-	-	-	-	-	-	-	-	-	-	-	-
Rural	-	-	-	-	-	-	-	-	-	-	-	-
Neversink River	-	-	-	-	117.5 2/	-	-	12.1 2/	64.5 2/	-	-	-
Lehigh River	3,100.0 5/	-	-	-	-	-	1,803.5 11/	1,627.6 11/	1,314.1 11/ 355.8 2/	-	-	-
Northampton	-	8.3 6/	-	-	-	-	66.5 11/	26.2 11/	7.4 11/ 2.8 6/	-	-	-
Allentown	-	577.0 7/***	-	-	-	-	364.4 11/	268.7 11/	138.7 11/ 24.0 7/	-	-	-
Bethlehem	-	-	-	-	-	-	1,028.7 11/ 35.0 2/	1,012.1 11/ 38.0 2/	344.5 11/	-	-	-
Freemansburg	-	10.1 9/	-	-	-	-	9.0 11/	5.1 11/	1.6 11/ .5 9/	-	-	-
Easton	-	-	-	-	-	-	121.6 11/	166.9 11/	548.6 11/	-	-	-
Catasauqua & Hokendauqua	-	-	-	-	-	-	46.9 11	33.6 11/	22.0 11/	-	-	-
Treichlers & Cementon	-	-	-	-	-	-	10.9 11/	3.3 11/	5.8 11/	-	-	-
Slatington & Walnutport	-	-	-	-	-	-	16.4 11/	5.0 11/	1.0 11/	-	-	-
Palmerton & Bowmanstown	-	-	-	-	-	-	15.2 11/	7.2 11/	1.5 11/	-	-	-
Weissport	-	-	-	-	-	-	12.6 11/	22.3 11/	25.2 11/	-	-	-
Lehighton	-	-	-	-	-	-	7.3 11/	14.6 11/	20.7 11/	-	-	-
Mauch Chunk	-	-	-	-	-	-	21.8 11/	.4 11/	.4 11/	-	-	-
Utilities												
Easton to Allentown	-	-	-	-	-	-	18.2 11/	38.4 11/	19.2 11/	-	-	-
Above Allentown to Lehighton	-	-	-	-	-	-	25.4 11/	16.5 11/	43.7 11/	-	-	-
Above Lehighton to White Haven	-	-	-	-	-	-	38.5 11/	7.3 11/	133.8 11/	-	-	-
Parryville to Mauch Chunk	-	-	-	-	-	-	-	-	-	-	-	-
Mauch Chunk to and incl. White Haven	-	-	-	-	-	-	-	-	-	-	-	-
Mauch Chunk Cr.(Mauch Chunk)	-	-	-	-	-	-	-	-	-	-	-	-
Black Creek (Weatherly)	-	-	-	-	-	-	-	-	-	-	-	-
Rancocas Creek	-	-	-	-	-	-	-	-	-	-	-	-
Mount Holly	-	-	-	-	-	-	-	-	-	51.0 4/**	1.7 4/	33.0
Schuylkill River	-	-	-	-	-	-	1,799.0 4/	-	19.8 2/	-	-	-
Reading	-	-	-	-	-	-	665.7 13/	-	2.1 13/	-	-	-
Birdsboro	-	-	-	-	-	-	127.5 13/	-	1.2 13/	-	-	-
Pottstown	-	-	-	-	-	-	120.8 13/	-	.5 13/	-	-	-
S.Pottstown & Kenilworth	-	-	-	-	-	-	43.4 13/	-	.3 13/	-	-	-
Spring City	-	-	-	-	-	-	24.4 13/	-	-	-	-	-
Royersford	-	-	-	-	-	-	57.9 13/	-	.2 13/	-	-	-
Phoenixville	-	-	-	-	-	-	19.8 13/	-	-	-	-	-
Norristown	-	-	-	-	-	-	121.6 13/	-	2.1 13/	-	-	-
Bridgeport	-	-	-	-	-	-	152.2 13/	-	1.5 13/	-	-	-
Conshohocken	-	-	-	-	-	-	14.7 13/	-	.2 13/	-	-	-
Manayunk	-	-	-	-	-	-	48.0 13/	-	-	-	-	-
Fairmount Park	-	-	-	-	-	-	81.4 13/	-	-	-	-	-

Reports Used as Sources:

1/ Preliminary Examination, Delaware River, 24 Mar 1932. H.D. 179, 73d Cong., 2d Sess.
2/ Preliminary Examination, Delaware River, 2 Mar 1938. Not published.
3/ Preliminary Examination, Delaware R. & Tributaries at and in vicinity of Morrisville, Bucks County, Pa., 28 Feb 1940. Not published.
4/ Survey, Delaware R., 15 Jan 1941. Not published.
5/ Preliminary Examination, Lehigh River, Pa., 25 Sep 1931. H.D. 245, 72d Cong., 1st Sess.
6/ Survey, Lehigh River at Northampton, Pa., 5 Aug 1937. Revised in H.D. 587, 79th Cong., 2d Sess.
7/ Survey, Lehigh River at Allentown, Pa., 15 Mar 1938. Revised in H.D. 587, 79th Cong., 2d Sess.
8/ Survey, Lehigh River and Monocacy Cr. at Bethlehem, Pa., 4 Nov 1[...] 79th Cong., 2d Sess.
9/ Survey, Lehigh R. at Freemansburg, Pa., 4 Aug 1937. Rev., H.D. [...]
10/ Survey, Lehigh R. at Easton, Pa., 8 Feb 1938. Rev., H.D. 587, 7[...]
11/ Survey, Delaware R. (Lehigh), 15 Nov 1944. H.D. 587, 79th Cong.,
12/ Survey, Delaware R. (Lackawaxen), 1 June 1944. H.D. 113, 80th C[...]
13/ Survey, Schuylkill River, 15 May 1937. H.D. 183, 76th Cong., 1s[...]

* Reduced to $457,300 in 4/. ** Direct damage only. *** Adjusted to 1938 conditions.

TABLE 3

D DAMAGE ESTIMATE IN PRIOR REPORTS

DELAWARE RIVER BASIN

usands of dollars, per date of flood occurrence)

	D A T E	O F	F L O O D						
	6 Oct 1932	28 Aug 1933	7-10 Jul 1935	12-18 Mar 1936	22 Sep 1938	4 Mar 1939	21 Aug 1939	1 Sep 1940	20-23 May 1942
	-	-	-	-	-	-	-	-	-
2/	163.5 2/	17.9 2/	13.4 2/	141.0 2/	-	-	-	-	-
	-	-	990.3 2/	40.5 2/	-	-	-	-	-
	-	-	2.5 2/	60.4 2/	-	-	-	-	-
	-	-	-	594.7 2/	-	-	-	-	-
	-	-	-	772.9 2/	-	-	-	-	-
	-	-	-	50.0 2/	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	22.3 4/**	-	-	-	-	-
				83.0 3/					
	-	-	-	72.5 3/	-	-	-	-	-
	-	-	-	688.8 2/*	-	-	-	-	6,202.5 12/
	-	-	-	-	-	-	-	-	103.5 12/
	-	-	-	-	-	-	-	-	211.0 12/
	-	-	-	211.7 4/**	2.6 4/**	-	-	-	3,976.5 12/
	-	-	-	-	-	-	-	-	22.0 12/
	-	-	-	-	-	-	-	-	1,085.0 12/
	-	-	-	-	-	-	-	-	804.5 12/
2/	-	-	12.1 2/	64.5 2/	-	-	-	-	-
	-	1,803.5 11/	1,627.6 11/	1,314.1 11/	-	-	-	-	10,406.8 11/
				355.8 2/					
	-	66.5 11/	26.2 11/	7.4 11/	-	-	-	-	215.7 11/
				2.8 6/					
	-	364.4 11/	268.7 11/	138.7 11/	-	-	-	-	986.4 11/
				24.0 7/					
	-	1,028.7 11/	1,012.1 11/	344.5 11/	-	-	-	-	5,037.4 11/
		35.0 2/	38.0 2/						
	-	9.0 11/	5.1 11/	1.6 11/	-	-	-	-	196.3 11/
				.5 9/					
	-	121.6 11/	166.9 11/	548.6 11/	-	-	-	-	298.7 11/
	-	46.9 11	33.6 11/	22.0 11/	-	-	-	-	424.8 11/
	-	10.9 11/	3.3 11/	5.8 11/	-	-	-	-	)
	-	16.4 11/	5.0 11/	1.0 11/	-	-	-	-	) 1,325.6 11/
	-	15.2 11/	7.2 11/	1.5 11/	-	-	-	-	)
	-	12.6 11/	22.3 11/	25.2 11/	-	-	-	-	195.5 11/
	-	7.3 11/	14.6 11/	20.7 11/	-	-	-	-	108.4 11/
	-	21.8 11/	.4 11/	.4 11/	-	-	-	-	138.7 11/
	-	18.2 11/	38.4 11/	19.2 11/	-	-	-	-	-
	-	25.4 11/	16.5 11/	43.7 11/	-	-	-	-	-
	-	38.5 11/	7.3 11/	133.8 11/	-	-	-	-	-
	-	-	-	-	-	-	-	-	762.6 11/
	-	-	-	-	-	-	-	-	716.7 11/
	-	-	-	-	-	-	-	-	34.7 11/
	-	-	-	-	-	-	-	-	9.2 11/
	-	-	-	-	-	-	-	-	-
	-	-	-	-	51.0 4/**	1.7 4/	33.0 4/	128.9 4/	-
	-	1,799.0 4/	-	19.8 2/	-	-	-	-	-
	-	665.7 13/	-	2.1 13/	-	-	-	-	-
	-	127.5 13/	-	1.2 13/	-	-	-	-	-
	-	120.8 13/	-	.5 13/	-	-	-	-	-
	-	43.4 13/	-	.3 13/	-	-	-	-	-
	-	24.4 13/	-	-	-	-	-	-	-
	-	57.9 13/	-	.2 13/	-	-	-	-	-
	-	19.8 13/	-	-	-	-	-	-	-
	-	121.6 13/	-	2.1 13/	-	-	-	-	-
	-	152.2 13/	-	1.5 13/	-	-	-	-	-
	-	14.7 13/	-	.2 13/	-	-	-	-	-
	-	48.0 13/	-	-	-	-	-	-	-
	-	81.4 13/	-	-	-	-	-	-	-

d Sess.

isville,

8/ Survey, Lehigh River and Monocacy Cr. at Bethlehem, Pa., 4 Nov 1938. Rev. H.D. 587, 79th Cong., 2d Sess.

9/ Survey, Lehigh R. at Freemansburg, Pa., 4 Aug 1937. Rev., H.D. 587, 79th Cong., 2d Sess.

10/ Survey, Lehigh R. at Easton, Pa., 8 Feb 1938. Rev., H.D. 587, 79th Cong., 2d Sess.

11/ Survey, Delaware R. (Lehigh), 15 Nov 1944. H.D. 587, 79th Cong., 2d Sess.

, 1st Sess.

12/ Survey, Delaware R. (Lackawaxen), 1 June 1944. H.D. 113, 80th Cong., 1st Sess.

9th Cong.,

13/ Survey, Schuylkill River, 15 May 1937. H.D. 183, 76th Cong., 1st Sess.

th Cong.,

ed to 1938 conditions.

TABLE 4

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE																SUMMARY OF DAMAGE			
	RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD					
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
EAST BRANCH DELAWARE AREA																				
East Br., Delaware R. Basin	.3		1.7	.6													2.0	.6		2.6
Beaver Kill	1.5		3.1	.4					.6								5.2	.4		5.6
Total for Area	1.8		4.8	1.0					.6								7.2	1.0		8.2
WEST BRANCH DELAWARE AREA																				
West Br., Delaware R. Basin																			3.2	3.2
Total for Area																			3.2	3.2
HANCOCK-PORT JERVIS AREA																				
Reach A-1 Delaware River																				
Barryville, N. Y.	17.3	.2	57.1	24.3					1.0								75.4	24.5	15.0	114.9
Damascus & Cochecton Twps. - Pa. & N. Y.													56.7	10.0			56.7	10.0	9.7	76.4
Lackawaxen Twp., Pa.													306.5	45.0	69.9	24.2	376.4	69.2	36.6	482.2
Highland Town, N. Y.	1.0		6.9										14.7	5.0			22.6	5.0	4.0	31.6
Subtotal Reach A-1 Delaware River	18.3	.2	64.0	24.3					1.0				377.9	60.0	69.9	24.2	531.1	108.7	65.3	705.1
Reach A-2 Delaware River																				
Pond Eddy, N. Y.-Pa.	83.2	1.2	4.8	1.0					6.7								94.7	2.2	13.7	110.6
Sparrowbush, N. Y. 1/	.8								1.2								2.0		13.6	15.6
Millrift, Pa. 1/	16.1	.7															16.1	.7		16.8
Port Jervis, N. Y. 1/	330.9	11.8	116.7	39.1	5.9	8.3	43.0	2.5	10.8	1.1			14.2	5.0			521.5	67.8	158.0	747.3
Matamoras, Pa.	21.6	.2	6.9	.1									2.0				30.5	.3	2.3	33.1
Shohola Twp., Pa.													13.2	5.0	96.5	26.6	109.7	31.6	12.5	153.8
Lumberland Town, N. Y.	14.0	.8	21.7	7.3									39.8	15.0			75.5	23.1	91.5	190.1
Deer Park Town, N. Y.			75.5	241.5									23.8	10.0			99.3	251.5		350.8
Subtotal Reach A-2 Delaware River	466.6	14.7	225.6	289.0	5.9	8.3	43.0	2.5	18.7	1.1			93.0	35.0	96.5	26.6	949.3	377.2	291.6	1618.1
Lackawaxen River Basin																				
Honesdale to Hawley (incl.)																				
Honesdale, Pa.	20.2				64.5	96.6	128.9						37.7	5.0			251.3	101.6	62.6	415.5
Hawley (Lackawaxen only), Pa.	104.2	2.0	250.2	158.4	.6	2.5	137.5	1.0	.9				189.5	4.0			682.9	167.9	52.0	902.8
Mt. Pleasant Twp., Pa.													12.6				12.6		.1	12.7
Clinton Twp., Pa.													29.1				29.1			29.1
Oregon Twp., Pa.													15.0				15.0		1.5	16.5
Berlin Twp., Pa.													81.0				81.0		7.4	88.4
Texas Twp., Pa.													22.5				22.5		4.4	26.9
Palmyra Twp. (Wayne Co.) Pa.													19.0				19.0		3.7	22.7
Dyberry Twp., Pa.																			1.4	1.4
Wayne County, Pa.																			110.5	110.5
Subtotal - Honesdale to Hawley	124.4	2.0	250.2	158.4	65.1	99.1	266.4	1.0	.9				406.4	9.0			1113.4	269.5	243.6	1626.5

1/ Damage due to Delaware River only.

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD		SUMMARY OF DAMAGE			
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
Lackawaxen River Basin (Cont'd)																				
Hawley to Mouth of River																				
Rowland, Pa.	70.0																70.0		3.5	73.5
Lackawaxen Twp., Pa.	18.3		59.0	7.0			538.0	150.0					172.3	13.0	296.5	54.9	1084.1	224.9		1309.0
Blooming Grove Twp., Pa.													8.8				8.8		.4	9.2
Pike County, Pa.																			37.9	37.9
Subtotal - Hawley to Mouth	88.3		59.0	7.0			538.0	150.0					181.1	13.0	296.5	54.9	1162.9	224.9	41.8	1429.6
Subtotal - Honesdale to Mouth	212.7	2.0	309.2	165.4	65.1	99.1	804.4	151.0					587.5	22.0	296.5	54.9	2276.2	494.4	285.4	3056.1
Dyberry Creek	2.5		3.0										30.4				35.9			35.9
Wallenpaupack Creek (Above Wallenpaupack Dam)																				
Greentown, Pa.	60.7		16.0								46.5	2.0	8.0				131.2	2.0		133.2
South Sterling, Pa.	123.0	.1	81.6	28.5									114.0				318.6	28.6		347.2
Newfoundland, Pa.	106.4	.5	284.8	99.3							14.3		23.0				428.5	99.8		528.3
Dreher Twp., Pa.			20.8	3.0							35.0	2.0	28.0				83.8	5.0	66.7	155.5
Salem Twp., Pa.													67.5				67.5		4.1	71.6
Sterling Twp., Pa.													390.5	5.0			390.5	5.0	4.9	400.4
Greene Twp., Pa.													300.0	5.0			300.0	5.0	10.7	315.7
Palmyra Twp. (Pike Co.), Pa.																			4.3	4.3
Wayne County, Pa.																			34.1	34.1
Pike County, Pa.																			79.2	79.2
Subtotal - Wallenpaupack Cr.	290.1	.6	403.2	130.8							95.8	4.0	931.0	10.0			1720.1	145.4	204.0	2069.5
Middle Creek *																				
Hawley, Pa. (Middle Cr. only)	7.3		6.8	1.9									33.5				47.6	1.9		49.5
Palmyra Twp., Pa. (Wayne Co.)													4.5				4.5			4.5
South Canaan Twp., Pa.																			10.7	10.7
Cherry Ridge Twp., Pa.																			.8	.8
Subtotal - Middle Creek	7.3		6.8	1.9									38.0				52.1	1.9	11.5	65.5
Subtotal - Lackawaxen River Basin	512.6	2.6	722.2	298.1	55.1	99.1	804.4	151.0			95.8	4.0	1586.9	32.0			4084.3	641.7	500.9	5227.0
Shohola Creek Basin	26.2										136.1	7.0	362.5	1.0	105.2	27.4	630.0	35.4		665.4
Mongaup River Basin																				
Liberty, N. Y.	3.5		51.9										68.0				123.4		.8	124.2
Remainder of basin													93.7	5.0			93.7	5.0	1.4	100.1
Subtotal - Mongaup River Basin	3.5		51.9								136.1	7.0	161.7	5.0			217.1	5.0	2.2	224.3

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD		SUMMARY OF DAMAGE			
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
HANCOCK-PORT JERVIS AREA (Cont'd.)																				
Neversink River Basin																				
Port Jervis, N. Y. (Neversink only)	66.7	.2	154.4	10.2													221.1	10.4		231.5
Monticello, N. Y.	5.8		44.0	4.6									9.1				58.9	4.6		63.5
Basher Kill	59.9		38.5	14.1	28.6	6.5	6.3						242.8	5.0			376.1	25.6	66.5	468.2
Remainder of Neversink	29.2		58.3	113.0							.8		166.8	35.0			255.1	148.0	67.6	470.7
Subtotal - Neversink River Basin	161.6	.2	295.2	141.9	28.6	6.5	6.3				.8		418.7	40.0			911.2	188.6	134.1	1233.9
Minor Tributary Basins - Delaware River above Port Jervis	37.1		69.6	16.3			.5	.3	1.6		9.2		417.2	5.0			535.2	21.6	6.0	562.8
Total - Hancock-Port Jervis Area	1225.9	17.7	1428.5	769.6	99.6	113.9	854.2	153.8	22.2	1.1	241.9	11.0	3417.9	178.0	568.1	133.1	7858.3	1378.2	1000.1	10236.6
PORT JERVIS-BELVIDERE AREA																				
Reach B-1 - Delaware River																				
Milford, Pa.	31.5		48.0	11.5			3.7						30.0	15.0			113.2	26.5	14.4	154.1
Westfall Twp., Pa. (B-1 only)	22.8		37.3	14.7			8.0	3.0			40.4		6.0				114.5	17.7	8.0	140.2
Milford & Dingmans Twp., Pa.	2.5		13.0	5.0			15.0	5.0			90.4	5.0	25.2	10.0			147.1	26.0	18.0	191.1
Montague Twp., N. J.	59.2										194.5	10.0					253.7	10.0	10.0	273.7
Sandystone Twp., N. J. & Delaware Twp., Pa.	75.4		79.6	10.1			15.5	3.0					61.2	5.0			232.7	18.1	19.8	270.6
Lehman Twp., Pa.	28.5		112.9	28.0			8.0	3.0					31.0				180.4	31.0	12.3	223.7
Wallpack Twp., N. J.	93.4		22.3	.8							35.6	1.0					151.3	1.8	14.3	167.4
Middle Smithfield Twp., Pa.	1.8						5.0	3.0			19.5						29.3	3.0		32.3
Pahaquarry Twp., N. J.	90.6		216.0	34.4					1.4		18.7		12.6				339.3	34.4	4.2	377.9
Subtotal - Reach B-1, Delaware River	406.7		529.1	104.5			59.2	18.0	1.4		399.1	16.0	166.0	30.0			1561.5	168.5	101.0	1831.0
Reach B-2 - Delaware River																				
Delaware Water Gap, Pa.	52.4		17.1	3.3									.5				70.0	3.3	1.8	75.1
Columbia, N. J.	44.7	.4	8.8	2.3													53.5	2.7		56.2
Slateford, Pa.	75.5	.3															75.5	.3		75.8
Portland, Pa.	4.2		184.5	26.0	17.4	11.5							53.5	20.0			259.6	57.5		317.1
Belvidere, N. J.	99.2	.1	43.4	14.7									8.0				150.6	14.8	1.6	167.0
Smithfield Twp., Pa.	64.3	.4	252.8	59.2			[illegible]	2.7					10.0				346.6	62.8	6.3	415.7
Upper Mt. Bethel Twp., Pa.	125.2		48.6	13.5			15.0	3.0			18.[illegible]		118.1	15.0	.4		325.9	31.5		357.4
Knowlton & White Twps., N. J.	204.6	.7	117.2	24.3			30.0	[illegible]	20.0		.5				86.0		468.3	27.0	13.8	509.1
Subtotal - Reach B-2, Delaware River	670.1	1.9	682.4	143.3	17.4	11.5	54.5	[illegible]	20.0		19.1		190.1	35.0	86.4		1750.0	199.9	23.5	1973.4

TABLE 4 - Sheet 4

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE																SUMMARY OF DAMAGE			
	RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD		PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss				
PORT JERVIS-BELVIDERE AREA (Cont'd)																				
Bush Kill (Monroe Co.) Basin	152.1		216.7	75.3	186.0	21.0	1.0		27.6				279.2	186.0			862.6	282.3	5.8	1150.7
Flat Brook Basin	6.7		7.1	1.5							14.9	1.0	120.0				148.7	2.5	.2	151.4
Brodhead Creek Basin																				
Brodhead Creek																				
Stroudsburg, Pa. 2/	540.4	8.5	866.6	188.5	1052.1	474.6	330.0	10.0	59.7	6.0			463.4	5.0			3312.2	692.5	534.6	4539.4
East Stroudsburg, Pa.	1196.1	23.0	472.0	132.1	193.2	670.5	535.1	41.0	65.4				149.3	5.0	15.0	5.0	2626.1	876.6	744.3	4247.0
Remainder of Brodhead	752.1	12.5	1281.0	343.0	755.2	1298.8	52.2	13.1	15.4	.3	297.8	15.0	5012.2	485.0	2878.0	677.0	11043.9	2844.7	211.8	14100.4
Subtotal - Brodhead Cr.	2488.6	44.0	2619.6	663.6	2000.5	2443.9	917.3	64.1	140.5	6.3	297.8	15.0	5624.9	496.0	2893.0	682.0	16982.2	4413.9	1490.7	22886.8
Pocono Creek																				
Stroudsburg, Pa.	87.7	.3	39.6	30.1	288.5	74.5			58.5	19.0			232.2				707.5	123.9		831.4
Remainder of Pocono	87.8	1.3	153.1	60.1	1.0				35.7	2.4	79.6	4.0	1629.2	28.0			1986.4	95.8		2082.2
Subtotal - Pocono Cr.	175.5	1.6	192.7	90.2	289.5	74.5			94.2	21.4	79.6	4.0	1862.4	28.0			2693.9	219.7		2313.6
McMichael Creek	16.0		7.2	1.0									185.5	2.0			208.7	3.0		211.7
Subtotal - Brodhead Creek Basin	2680.1	45.6	2819.5	754.9	2290.0	2518.4	917.3	64.1	234.7	27.7	377.4	19.0	7672.8	525.0	2893.0	682.0	19884.8	4636.7	1490.7	26012.[illegible]
Paulins Kill Basin	74.3		129.4	31.6	101.3	24.0	50.0		4.0		50.0	2.0	1354.7	10.0	165.0	157.0	1928.7	224.6	26.9	2180.2
Pequest River Basin										1.3	203.6	10.0					203.4	11.3		214.9
Minor Tributary Basins, Port Jervis-Belvidere Area	19.6		29.8	19.0	34.5	21.0							732.4				816.3	40.0		856.3
Total - Port Jervis-Belvidere Area	4009.6	47.5	4414.0	1130.0	2629.2	2595.9	1082.0	90.3	297.7	29.0	1064.1	48.0	10515.2	786.0	3144.4	839.0	27156.2	5565.7	1648.1	34370.0
BELVIDERE-TRENTON AREA																				
Reach C-1 - Delaware River																				
Foul Rift, N. J. & Pa.	150.0																150.0		1.3	151.3
Hutchinson, N. J.	230.8		26.5	5.5													257.3	5.5	25.0	287.8
Lower Mt. Bethel Twp., Pa.	539.8	.3	106.2	60.1	13.0		42.0	3.0					11.3	5.0	1.5		713.8	68.4	37.1	8[illegible]9.3
Harmony Twp., N. J.	356.8						15.0	1.0			5.8				86.0		463.6	1.0	25.0	489.6
Forks Twp., Pa.	399.4	1.2	58.5	8.6			15.0	3.0					1.8		1.5		476.2	12.8		489.0
Subtotal - Reach C-1 - Delaware River	1676.8	1.5	191.2	74.2	13.0		72.0	7.0			5.8		13.1	5.0	89.0		2060.9	87.7	88.4	2237.0

2/ Damage due to Brodhead Creek only.

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD		SUMMARY OF DAMAGE			
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
BELVIDERE-TRENTON AREA (Cont'd.)																				
Reach C-2 - Delaware River																				
Phillipsburg, N. J.	33.8		179.2	99.5	100.2	43.0	207.2	1.5	43.5					106.0			653.9	250.0	99.6	1003.5
Easton, Pa. (Del. R. only)	436.3	1.5	1696.6	641.8	323.2	94.0	597.0	22.5	20.0				574.8	101.0			3647.9	860.8	507.5	5016.2
Raubsville, Pa.	203.5		25.4	11.8					5.0				11.9				245.8	11.8	5.6	263.2
Riegelsville, Pa. & N. J.	269.3		134.5	30.2	297.8	73.2	8.6		3.3				1.8	1.0			715.3	104.4	85.5	905.2
Williams & Palmer Twps., Pa.	42.4	.6	13.2				30.0	12.0	25.0				11.5	5.0			122.1	17.6	.9	140.6
Lopatcong Twp., N. J.					9.2	15.5	5.0	1.0							86.0		100.2	16.5	25.0	141.7
Pohatcong Twp., N. J.	299.0		153.5	29.2			15.0	1.0			10.9						478.4	30.2	27.7	536.3
Subtotal Reach C-2 - Delaware River	1284.3	2.1	2202.4	812.5	820.4	225.7	662.8	38.0	90.8		10.9		600.0	213.0	86.0		5903.6	1291.3	751.8	8006.7
Reach D - Delaware River																				
Kintnersville, Pa.	72.5		14.5	6.3													87.0	6.3	24.5	117.8
Upper Black Eddy, Pa.	143.8		49.6	21.6			8.6		4.0								206.0	21.6	81.1	308.7
Frenchtown, N. J.	97.3	.1	105.8	39.5	29.4	52.4							5.0				237.5	92.0	1.9	331.4
Byram, N. J.	87.2																87.2			87.2
Lumberville, Pa.	18.2		191.4	58.0													209.6	58.0		267.6
Stockton, N. J.	84.2	.4	121.0	36.0									5.0				210.2	36.4	6.5	253.1
Lambertville, N. J.	130.9	.2	370.7	95.0	179.9	114.0								85.0			681.5	294.2	189.3	1165.0
New Hope, Pa.	229.7	3.8	331.6	205.2	165.0	200.0							94.3	85.0			820.6	495.0	183.1	1498.7
Yardley, Pa.	794.6	35.6	136.0	29.9	20.0	6.4	67.4						1180.0	496.0			2198.0	567.9	425.8	3191.7
Trenton, N. J.	1399.8	6.4	574.6	135.8	241.5	304.8	20.0	1.0	112.1	2.0			9.7	5.0			2357.7	456.0	1086.6	3900.3
Morrisville, Pa.	18.9				35.0	1.0											53.9	1.0		54.9
Holland Twp., N. J.	8.0		45.1	4.1	660.0	358.6	101.0	1.0			19.2		9.6	5.0			842.9	368.7	4.1	1215.7
Alexandria & Kingwood Twps., N. J.			94.5	6.0			15.0	1.0	5.0		40.8	5.0	7.4				162.7	12.0	2.3	177.0
Durham Twp., Pa.	3.8		70.0	10.7			15.0	6.0	25.0		6.7		3.5				124.0	16.7	4.2	144.9
Nockamixon Twp., Pa.			4.5	1.2			17.0	3.0	20.0								41.5	4.2	4.0	49.7
Bridgeton Twp., Pa.							17.0	3.0	15.0				5.3				37.3	3.0	4.8	45.1
Tinicum Twp., Pa.	80.2		98.8	8.5			17.0	3.0	25.0		35.3		8.0				264.3	11.5	5.6	281.4
Plumstead Twp., Pa.	37.9		45.0	5.9			15.0	3.0	23.0				60.3	20.0			181.2	28.9	15.1	225.2
Delaware & W. Amwell Twp., N. J.	25.3	.4					35.0	2.0			94.4	10.0	36.6	10.0			191.3	22.4	4.8	218.5
Solebury Twp., Pa.	81.8	.3	.9						20.0		7.8		11.8				122.3	.3	41.3	163.9
Hopewell Twp., N. J.	23.2		.7	.5			15.0	1.0	20.0								58.9	1.5	.9	61.3
Upper Makefield Twp., Pa.	391.3	3.8	42.2	6.6					35.0		2.0		65.7	20.0			536.2	30.4	25.9	592.5
Lower Makefield Twp., Pa.	247.6	.5							10.0				5.7				263.3	.5	121.3	385.1
Ewing Twp., N. J.	105.1	.8	235.1	125.7			10.0		108.3								458.5	126.5	6.1	591.1
Subtotal - Reach D - Delaware River	4081.3	52.3	2532.0	798.5	1330.8	1037.2	353.0	24.0	422.4	2.0	206.2	15.0	1507.9	726.0			10433.6	2655.0	2239.2	15327.8

TABLE 4 - Sheet 6

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL Physical	RESIDENTIAL Business Loss	COMMERCIAL Physical	COMMERCIAL Business Loss	INDUSTRIAL Physical	INDUSTRIAL Business Loss	UTILITIES Physical	UTILITIES Business Loss	PUBLIC Physical	PUBLIC Business Loss	RURAL Physical	RURAL Business Loss	HIGHWAY Physical	HIGHWAY Business Loss	RAILROAD Physical	RAILROAD Business Loss	SUMMARY OF DAMAGE: PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
BELVIDERE-TRENTON AREA (Cont'd.)																				
Bushkill Creek Basin													31.6	1.0			31.6	1.0	2.0	34.6
Pohatcong Creek Basin	2.0								3.2		7.0	1.0					12.2	1.0		13.2
Musconetcong River Basin	23.0	.1	4.8	.8			5.0				6.4						39.2	.9	.6	40.7
Tohickon Creek Basin													8.5	1.0			8.5	1.0	1.2	10.7
Delaware & Raritan Canal Basin																			40.4	40.4
Minor Tributary Basins, Belvidere-Trenton Area	18.8		19.3	1.8							2.7		8.8				49.6	1.8	2.0	53.4
Total - Belvidere-Trenton Area	7086.2	56.0	4949.7	1687.8	2164.2	126.9	1292.8	69.0	522.4	2.0	239.0	16.0	2169.9	946.0	175.0		18599.2	4039.7	3125.6	25764.5
TRENTON TO MOUTH AREA																				
Reach E - Delaware River																				
Fairless Hills, Pa.					350.0												350.0			350.0
Bristol, Pa.			9.4	.7													9.4	.7	1.6	11.7
Bordentown, N. J.	19.2		37.8	15.4													57.0	15.4		72.4
Florence-Roebling, N. J.			.2		.9	12.0							1.4				2.5	12.0	1.4	15.9
Burlington, N. J.	129.3		180.2	41.4	14.8	16.3	3.0		69.1				45.0	10.0			441.4	67.7	35.1	544.2
Falls Twp., Pa.									39.0				29.4				68.4			68.4
Hamilton Twp., N. J.	23.7		93.5	13.2													117.2	13.2		130.4
Bordentown Twp., N. J.													2.4				2.4			2.4
Subtotal - Reach E - Delaware R.	172.2		321.1	70.7	365.7	28.3	3.0		108.1				78.2	10.0			1048.3	109.0	38.1	1195.4
Reach F - Delaware River																				
Riverside, N. J.	8.7																8.7			8.7
Camden, N. J.			8.1	4.4			1.0							15.0			9.1	19.4	17.5	46.0
Westville, N. J.	30.6												2.0				32.6			32.6
Chester, Pa.					50.0												50.0			50.0
Bensalem Twp., Pa.	7.8																7.8		1.2	9.0
Beverly Twp., N. J.																			2.2	2.2
Cinnaminson Twp., N. J.	2.2																2.2			2.2
Pensauken Twp., N. J.							4.5						33.3				37.8			37.8
Center Twp., N. J.	2.0		2.4	.8									16.6				21.0	.8		21.8
Tinicum Twp., Pa.			6.0				38.0										44.0			44.0
Greenwich Twp., N. J.									13.1								13.1		.6	13.7
Logan Twp., N. J.	0.8																0.8			0.8
Subtotal - Reach F - Delaware R.	52.1		16.5	5.2	50.0		43.5		13.1				51.9	15.0			227.1	20.2	21.5	268.8

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL Physical	RESIDENTIAL Business Loss	COMMERCIAL Physical	COMMERCIAL Business Loss	INDUSTRIAL Physical	INDUSTRIAL Business Loss	UTILITIES Physical	UTILITIES Business Loss	PUBLIC Physical	PUBLIC Business Loss	RURAL Physical	RURAL Business Loss	HIGHWAY Physical	HIGHWAY Business Loss	RAILROAD Physical	RAILROAD Business Loss	SUMMARY OF DAMAGE: PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
TRENTON TO MOUTH AREA (Cont'd.)																				
Neshaminy Creek Basin	331.6		59.0	27.7	111.5	5.5			38.0	12.4			61.1	1.0			601.2	46.6	24.2	672.0
Rancocas Creek Basin			.8	.2													.8	.2		1.0
Pennypack Creek Basin									29.7				7.6	1.0			37.3	1.0		38.3
Cobbs Creek Basin	4.8		122.8	4.9	75.0	115.7			231.7				11.5	2.0	15.0		460.8	123.6		584.4
Darby Creek Basin	104.6	.3	247.4	49.0	315.0	88.2			8.0				39.3	1.0			714.3	138.5	17.3	870.1
Crum Creek Basin	3.5		11.3	.5	211.9	45.3			12.1				3.9				242.7	45.8		288.5
Ridley Creek Basin					6.7				.6				4.9				12.2			12.2
Chester Creek Basin	4.2																4.2			4.2
Total - Trenton to Mouth Area	673.0	.3	778.9	158.2	1135.8	284.0	46.5		441.3	12.5			258.4	30.0	15.0		3348.9	484.9	101.1	3934.9
LEHIGH RIVER BASIN																				
Lehigh R. - Above Bear Creek																				
Subtotal - Local Area	6.7												6.8				13.5		2.0	15.5
Lehigh R. - Bear Creek to Jim Thorpe, Incl.																				
White Haven, Pa.			22.5	2.0	37.5	21.2			1.2				12.0				73.2	23.2	1.4	97.8
Jim Thorpe, Pa.	1.0		1.1	.5	7.1	4.7	3.0	5.0									12.2	10.2	.4	22.8
Local Area													16.0		8.0	2.0	24.0	2.0		26.[illegible]
Subtotal - Bear Creek to Jim Thorpe	1.0		23.6	2.5	44.6	25.9	3.0	5.0	1.2				28.0		8.0	2.0	109.4	35.4	1.8	146.[illegible]
Lehigh R. - Jim Thorpe to Lehigh Gap																				
Lehighton, Pa.			9.3	2.2			1.0	1.0					12.0				22.3	3.2		25.5
Weissport, Pa.	124.9		12.0	39.4	60.6	40.2			7.4				7.2	2.0			212.1	81.6	7.2	300.9
Bowmanstown & W. Bowmanstown, Pa.					21.7	8.1							18.0				39.7	8.1		47.8
Palmerton, Pa.					9.6	14.7	100.0										109.6	14.7		124.3
Local Area													7.5		16.0	4.0	23.5	4.0		27.5
Subtotal - Jim Thorpe to Lehigh Gap	124.9		21.3	41.6	91.9	63.0	101.0	1.0	7.4				44.7	2.0	16.0	4.0	407.2	111.6	7.2	526.0
Lehigh R. - Lehigh Gap to Catasauqua, incl.																				
Slatington, Pa.	.6		3.9		6.3	30.5			2.5								13.3	30.5		43.8
Walnutport, Pa.	6.6		1.4	.3	7.1	4.7			5.0								20.1	5.0		25.1
Treichlers, Pa.	2.6		24.6	48.0	7.1	4.7											34.3	52.7		87.0
Northampton, Pa.	48.5		15.0	7.1	7.1	4.8	2.5	2.2									73.1	14.1	6.6	93.8
Catasauqua, Pa.	6.1		19.8	2.1	476.5	284.1											502.4	286.2		788.7
Local Area													2.3		20.0	5.0	22.3	5.0		27.3
Subtotal - Lehigh Gap to Catasauqua	64.4		64.7	57.5	504.1	328.8	2.5	2.2	7.5				2.3		20.0	5.0	665.5	393.5	6.6	1065.6
Lehigh R. - Catasauqua to Mouth																				
Allentown, Pa. 3/	40.5	.1	203.5	144.9	121.2	75.9	56.5		25.0				5.0	9.0	670.1	182.7	1121.8	412.6	16.8	1551.2

3/ Damage due to Lehigh River only.

TABLE 4 - Sheet 8

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD		SUMMARY OF DAMAGE			
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
LEHIGH RIVER BASIN (Cont'd.)																				
Lehigh R. - Catasauqua to Mouth (Cont'd.)																				
Bethlehem, Pa. 3/	40.4		216.2	52.6	2845.4	9093.6	39.0						4.1	4.0	699.4	228.8	3844.5	9379.0	46.1	13269.6
Freemansburg, Pa. 3/	48.9	.6	18.3	5.9	7.1	4.7			17.1						4.0	1.0	95.4	12.2	5.6	113.2
Easton, Pa. 3/			170.8	18.1	1247.4	1452.0									670.1	182.7	2088.3	1652.8	3.7	3744.8
Local Area													10.2				10.2			10.2
Subtotal - Lehigh R., Catasauqua to Mouth	129.8	.7	608.8	221.5	4221.1	10626.2	95.5		42.1				19.3	13.0	2043.6	595.2	7160.2	11456.6	72.2	18689.0
Pohopoco Cr. Basin													22.4	1.0			22.4	1.0	2.4	25.8
Mahoning Cr. Basin													27.0				27.0		2.0	29.0
Lizard Cr. Basin													28.9				28.9			28.9
Aquashicola Cr. Basin													52.6	3.0			52.6	3.0	1.9	57.5
Hokendauqua Cr. Basin					2.8	2.0											2.8	2.0		4.8
Jordan Cr. Basin																				
Allentown, Pa. (Jordan Cr. only)	12.0	.2	87.6	11.7	122.5	127.9											222.1	139.8		361.9
Minor Tributaries (Jordan Cr. only)													6.6				6.6			6.6
Little Lehigh Cr.																				
Allentown, Pa. (L. Lehigh Cr. only)	16.7		202.0	28.8	128.6	71.6							2.0				349.3	100.4		449.7
Minor Tributaries (L. Lehigh Cr. only)													64.3				64.3			64.3
Monocacy Cr. Basin																				
Bethlehem, Pa. (Monocacy Cr. only)	25.0		109.7	20.0	8.1	6.2							.2				143.0	26.2		169.2
Minor Tributaries of Lehigh R.	4.6		167.8										1167.6	30.0			1340.0	30.0	7.7	1377.7
Total - Lehigh River Basin	385.1	.9	1285.5	383.6	5123.7	11251.6	202.0	8.2	58.2				1472.7	49.0	2087.6	606.2	10614.8	12299.5	103.8	23018.1
SCHUYLKILL RIVER BASIN																				
Reach 0 - Fairmount Dam to Mouth																				
Essington & F. Mifflin, Pa.									30.0								30.0			30.0
Local Area																				
Subtotal - Reach 0									30.0								30.0			30.0
Reach I - City Line Br. to Fairmount Dam																				
Philadelphia, Pa.					2.8				160.0								162.8			162.8
Local Area							46.8								14.0		60.8			60.8
Subtotal - Reach I					2.8		46.8		160.0						14.0		223.6			223.6

3/ Damage due to Lehigh River only.

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA Stream Basin Locality	TYPES OF DAMAGE RESIDENTIAL Physical	 RESIDENTIAL Business Loss	 COMMERCIAL Physical	 COMMERCIAL Business Loss	 INDUSTRIAL Physical	 INDUSTRIAL Business Loss	 UTILITIES Physical	 UTILITIES Business Loss	 PUBLIC Physical	 PUBLIC Business Loss	 RURAL Physical	 RURAL Business Loss	 HIGHWAY Physical	 HIGHWAY Business Loss	 RAILROAD Physical	 RAILROAD Business Loss	SUMMARY OF DAMAGE PHYSICAL	 BUSINESS LOSS	 EMERGENCY COST	 TOTAL DAMAGE
SCHUYLKILL RIVER BASIN (Cont'd.)																				
Reach 2 - Spring Mill Rd. to City Line Br.																				
Manayunk, Pa.	.7				163.5	22.0											164.2	22.0		186.2
Miquon, Pa.					100.0	76.4											100.0	76.4		176.4
Roseglen, Pa.			1.1														1.1			1.1
Local Area							46.8						19.6		14.0		80.4		1.7	82.0
Subtotal - Reach 2	.7		1.1		263.5	98.4	46.8						19.6		14.0		345.7	98.4	1.7	445.8
Reach 3 - W. Conshohocken to Spring Mill Rd.																				
Conshohocken & W. Conshohocken, Pa.					24.3	57.2											24.3	57.2		81.5
Local Area							46.8								14.0		60.8			60.8
Subtotal - Reach 3					24.3	57.2	46.8								14.0		85.1	57.2		142.3
Reach 4 - Black Rock Dam to W. Conshohocken																				
Phoenixville, Pa.					3.4												3.4			3.4
Norristown & W. Norriton, Pa.	64.4																64.4		76.5	140.9
Bridgeport, Pa.					12.0	30.0											12.0	30.0		42.0
Local Area					10.8		46.8								14.0		71.6			71.6
Subtotal - Reach 4	64.4				26.2	30.0	46.8								14.0		151.4	30.0	76.5	257.9
Reach 5 - Birdsboro to Black Rock Dam																				
Royersford, Pa.					.5												.5			.5
Spring City, Pa.			1.0														1.0			1.0
Pottstown, Pa.	9.6				8.2		.6						1.2	1.0			19.6	1.0	26.3	46.9
Birdsboro, Pa.																			28.2	28.2
Parkerford, Pa.	1.6																1.6			1.6
Kenilworth, Pa. + N. Coventry Twp., Pa.																			2.5	2.5
W. Pottsgrove Twp., Pa. & Upper Potts., Pa.																			.9	.9
Amity Twp., Pa.																			1.6	1.6
Union Twp., Pa.	2.7																2.7			2.7
Limerick Twp., Pa.																				
Schuylkill Twp., Pa.																				
Local Areas	.1		.2				46.8						10.5		14.0		71.6			71.6
Subtotal - Reach 5	14.0		1.2		8.7		47.4						11.7	1.0	14.0		97.0	1.0	59.5	157.5

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD		SUMMARY OF DAMAGE			
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
SCHUYLKILL RIVER BASIN (Cont'd.)																				
Reach 6 - Leesport to Birdsboro																				
Reading, Pa.			3.2	1.6									.4				3.6	1.6	1.8	7.0
Leesport, Pa.													.4				.4			.4
Muhlenberg Twp., Pa.	.5																.5		13.0	13.5
Ontelaunee, Pa.													.3				.3			.3
Robeson Twp., Pa. + Exeter Twp., Pa.													.3				.3		1.2	1.5
Local Area							1.7								14.0		15.7			15.7
Subtotal - Reach 6	.5		3.2	1.6			1.7						1.4				20.8	1.6	16.0	38.4
Reach 7 - Port Clinton to Leesport																				
Mohrsville, Pa.	3.1												.3				3.4			3.4
Shoemakersville, Pa.																				
Center Twp., Pa.																				
Local Areas																			1.0	1.0
Subtotal - Reach 7	3.1												.3				3.4		1.0	4.4
Reach 8 - Middleport to Port Clinton																				
Landingsville, Pa.																				
Port Carbon, Pa.																			.1	.1
New Philadelphia, Pa.																				
Middleport, Pa.																				
Local Area																				
Subtotal - Reach 8																			.1	.1
Reach 9 - Above Middleport																				
Little Schuylkill River Basin																				
Tamaqua, Pa.	106.9		339.8	92.9	79.0	60.0	31.5		139.3				102.4	6.0			798.9	158.9	78.4	1036.2
Panther Creek													51.6	1.0	81.0	21.9	132.6	22.9	.6	156.1
Locust Creek													12.2				12.2			12.2
Local Area	6.0		22.5	9.3	746.0	65.0							289.2	1.0	756.0		1819.7	75.3	10.4	1905.4
Subtotal - Little Schuylkill	112.9		362.3	102.2	825.0	125.0	31.5		139.3				455.4	8.0	837.0	21.9	2763.4	257.1	89.4	3109.9

TABLE 4 (Cont'd.)

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955
(all values in thousands of dollars - 1955)

AREA / Stream Basin / Locality	TYPES OF DAMAGE: RESIDENTIAL		COMMERCIAL		INDUSTRIAL		UTILITIES		PUBLIC		RURAL		HIGHWAY		RAILROAD		SUMMARY OF DAMAGE			
	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	Physical	Business Loss	PHYSICAL	BUSINESS LOSS	EMERGENCY COST	TOTAL DAMAGE
SCHUYLKILL RIVER BASIN (Cont'd.)																				
West Branch Schuylkill River Basin													447.3				447.3			447.3
Maiden Creek Basin	2.1		1.3										103.7				107.1		2.8	109.9
Manatawney Cr. Basin	3.2		4.0	.5	7.7				.7				85.2	1.0			100.8	1.5	3.1	105.4
Bernhart Creek Basin					22.8	16.0											22.8	16.0		38.8
Tulpehocken Cr. Basin													16.4				16.4		5.6	22.0
French Creek Basin	3.1												2.9				6.0		.4	6.4
Perkiomen Creek Basin	15.2		2.7	.2							6.5	1.0	11.9				36.3	1.2	2.7	40.2
Stony Cr. Basin (Norristown)			62.1	8.5	68.1	7.0											130.2	15.5	.7	146.4
Sawmill Run Basin (Norristown)	12.8		252.2	18.7					88.1				50.0	1.0			403.1	19.7		422.8
Wissahickon Cr. Basin			.2		18.1				228.6				159.9				406.8		5.8	412.6
Minor Tributary Basins of Schuylkill R.	2.0												69.5				71.5		7.2	78.7
Total - Schuylkill River Basin	234.0		690.3	131.7	1267.2	333.6	267.8		646.7		6.5	1.0	1435.2	11.0	921.0	21.9	5468.7	499.2	272.5	6240.4
CHRISTINA RIVER BASIN																				
Brandywine Creek	16.4		34.3	7.3	433.2	559.0			13.0				66.0				562.9	566.3	10.9	1140.1
GRAND TOTAL - DELAWARE RIVER BASIN	13632.0	122.4	13586.0	4269.2	12852.9	16400.9	3745.3	321.3	2002.1	44.5	1551.5	76.0	19335.3	2000.0	6911.1	1600.2	73616.2	24834.5	6265.3	104716.0

TANGIBLE DAMAGES
DELAWARE

(All

State	County	Residential		Commercial		Industrial		Utilities		Ph
		Physical	Business	Physical	Business	Physical	Business	Physical	Business	Phy
New York	Delaware	.3		14.8	.9					
	Sullivan	185.3	2.2	257.6	155.3	28.6	6.5			
	Orange	462.8	12.0	410.0	304.2	6.0	8.2	49.3	2.5	1
	State Total	648.4	14.2	682.4	460.4	34.6	14.7	49.3	2.5	2
New Jersey	Camden	2.0		10.5	5.2			5.5		
	Sussex	277.0		202.0	27.0	55.0	4.0	15.5	3.0	
	Gloucester	31.4								1
	Warren	1570.6	1.2	788.4	228.0	245.7	78.5	322.2	6.5	8
	Hunterdon	437.7	1.1	737.0	180.6	1037.0	598.3	156.0	4.0	
	Mercer	1551.8	7.2	904.0	276.2	241.5	304.8	45.0	2.0	24
	Burlington	159.3		219.1	57.0	15.7	28.3	3.0		6
	State Total	4029.8	9.5	2861.0	774.0	1594.9	1013.9	547.2	15.5	40
Penna.	Wayne	355.5	2.7	647.2	291.0	65.0	99.1	266.4	1.0	
	Pike	371.3	.9	454.7	135.5	46.5	22.0	575.2	162.3	
	Monroe	2983.5	46.4	3373.9	854.4	2464.0	2538.4	934.8	70.3	26
	Northampton	1857.3	4.2	2446.0	865.2	3766.0	10122.1	740.5	45.7	7
	Bucks	2740.1	43.9	1204.0	415.1	811.5	212.9	165.7	18.0	2
	Philadelphia					186.1	80.4	84.7		53
	Montgomery	107.9		318.3	27.4	239.4	171.6	187.6		8
	Delaware	127.1	.4	402.2	57.4	638.6	190.8			16
	Lackawanna	6.7								
	Carbon	125.9		22.3	42.1	99.0	67.8	104.0	6.0	
	Luzerne	4.6		22.5	2.0	37.5	21.2			
	Lehigh	141.2	.2	760.0	236.1	1574.9	1146.0	56.6		2
	Chester	11.2		20.7	4.3	363.1	526.0			1
	Berks	8.5		8.6	2.1	22.8	16.0	1.8		
	Schuylkill	113.0		362.2	102.2	825.0	125.0	31.5		13
	State Total	8953.8	98.7	10042.6	3034.8	11139.4	15339.3	3148.8	303.3	157
Delaware	New Castle					84.0	33.0			
	State Total					84.0	33.0			
	BASIN TOTAL	13632.0	122.4	13586.0	4269.2	12852.9	16400.9	3745.3	321.3	200

TABLE 5

TANGIBLE DAMAGES FOR THE FLOOD OF 18-20 AUGUST 1955 BY COUNTY AND STATE
DELAWARE RIVER BASIN - SURVEY OF OCTOBER - DECEMBER 1955

(All values in thousands of dollars - 1955)

Utilities		Public		Rural		Highway		Railroad		Sub-Totals	
Physical	Business	Physical	Business	Physical	Business	Physical	Business	Physical	Business	Physical Damage	Business Loss
										15.1	.9
		9.1				642.3	60.0			1122.9	224.0
49.3	2.5	12.8	1.1	10.0		398.5	25.0			1394.4	353.0
49.3	2.5	21.9	1.1	10.0		1040.8	85.0			2487.4	577.9
5.5						49.9	15.0			67.9	20.2
15.5	3.0	1.8		244.9	12.0	708.2	6.5			1504.4	52.5
		13.1				2.0				46.5	
322.2	6.5	80.3	1.3	303.0	13.0	1125.3	114.5	423.0	157.0	4858.5	600.0
156.0	4.0	5.0		154.3	15.0	65.5	101.0			2592.5	900.0
45.0	2.0	240.4	2.0			9.7	5.0			2992.4	597.2
3.0		69.1				48.8	10.0			515.0	95.3
547.2	15.5	409.7	3.3	702.2	40.0	2009.4	252.0	423.0	157.0	12577.2	2265.2
266.4	1.0	.8		49.3	2.0	1084.3	24.0			2468.5	419.8
575.2	162.3			313.4	14.0	1962.7	215.9	649.1	155.0	4372.9	705.6
934.8	70.3	262.3	27.7	396.9	19.0	8824.8	589.1	2893.0	682.0	22133.2	4827.3
740.5	45.7	72.1		18.7		840.3	151.0	1396.9	417.5	11137.8	11605.7
165.7	18.0	257.3	12.4	54.5		1542.5	623.0			6775.6	1325.3
84.7		532.5				165.1	1.0	14.0		982.4	81.4
187.6		88.1		6.5	1.0	93.1	2.0	56.0		1096.9	202.0
		168.2				54.8	3.0	15.0		1405.9	251.6
										6.7	
104.0	6.0	7.4				335.1	36.0	24.0	6.0	717.7	157.9
		1.2								65.8	23.2
56.6		27.5				112.9	9.0	670.1	182.7	3343.2	1574.0
		13.0				72.3				480.3	530.3
1.8		.8				280.1	1.0	14.0		336.6	19.1
31.5		139.3				917.1	8.0	756.0		3144.1	235.2
3148.8	303.3	1570.5	40.1	839.3	36.0	16285.1	1663.0	6488.1	1443.2	58467.6	21958.4
										84.0	33.0
										84.0	33.0
3745.3	321.3	2002.1	44.5	1551.5	76.0	19335.3	2000.0	6911.1	1600.2	73616.2	24834.5

3

ilroad		Sub-Totals			
l	Business	Physical Damage	Business Loss	Emergency Loss	Grand Total
		15.1	.9		16.0
		1122.9	224.0	272.5	1619.4
		1394.4	353.0	171.7	1874.1
		2487.4	577.9	444.2	3509.5
		67.9	20.2	17.5	105.6
		1504.4	52.5	44.3	1601.2
		46.5		.6	47.1
	157.0	4858.5	600.0	250.1	5708.6
		2592.5	900.0	209.5	3702.0
		2992.4	597.2	1134.0	4723.6
		515.0	95.3	38.7	649.0
	157.0	12577.2	2265.2	1694.7	16537.1
		2468.5	419.8	373.4	3261.7
	155.0	4372.9	705.6	240.0	5318.5
	682.0	22133.2	4827.3	1505.9	28466.4
	417.5	11137.8	11605.7	570.2	23313.7
		6775.6	1325.3	1052.4	9153.3
		982.4	81.4		1063.8
		1096.9	202.0	146.9	1445.8
		1405.9	251.6	17.3	1674.8
		6.7		2.0	8.7
	6.0	717.7	157.9	17.5	893.1
		65.8	23.2	1.4	90.4
	182.7	3343.2	1574.0	62.9	4980.1
		480.3	530.3	11.6	1022.2
		336.6	19.1	35.5	391.2
		3144.1	235.2	89.4	3468.7
	1443.2	58467.6	21958.4	4126.4	84552.4
		84.0	33.0		117.0
		84.0	33.0		117.0
	1600.2	73616.2	24834.5	6265.3	$104716.0

TABLE 5

TABLE 6

CALCULATION OF TOTAL RECURRING DAMAGE - DELAWARE RIVER REACH C-1

Flood of August 1955

Class	(1) Original Data Survey - Oct-Dec 1955	(2)	(3) Business and Emergency Losses	(4) Subtotal	(5)	(6) Escalated Subtotal (Aug 1955 - June 1958)	(7)	(8) Supplemental Data	(9) Total	(10)
	Direct Losses 1/	Indirect Losses 1/	Computed by % of Physical Damages	Column 1 + 2	Column 1 + 3	Column 4 x 1.085	Column 5 x 1.085	Survey of Aug-Sept 1958	Column 6 + 8	Column 7 + 8
Residential	1,677,000	1,500	251,600	1,678,500	1,928,600	1,821,200	2,092,500	99,700	1,920,900	2,192,200
Commercial	191,200	74,200	70,700	265,400	261,900	288,000	284,200	83,000	371,000	367,200
Industrial	13,000	-	5,800	13,000	18,800	14,100	20,400	675,000	689,100	695,400
Utility	72,000	7,000	7,200	79,000	79,200	85,700	85,900	-	85,700	85,900
Public	-	-	-	-	-	-	-	100	100	100
Agricultural	5,800	-	600	5,800	6,400	6,300	6,900	6,400	12,700	13,300
Highway	13,100	5,000	3,300	18,100	16,400	19,600	17,800	4,100	23,700	21,900
Railroad	89,000	-	20,500	89,000	109,500	96,600	118,800	-	96,600	118,800
Aid & Relief										
Red Cross	-	51,300	2/	51,300	-	55,700	-	-	55,700	-
Operation NOAH	37,100	-	-	37,100	37,100	40,300	40,300	-	40,300	40,300
TOTALS	2,098,200	139,000	359,700	2,237,200	2,457,900	2,427,500	2,666,800	868,300	3,295,800	$3,535,100 (Adopted Reach Total)

1955 Flood Stage + 3 Feet (Hypothetical Flood)

Class	(1) Original Data Survey - Oct-Dec 1955	(2)	(3) Business and Emergency Losses	(4)	(5) Subtotal	(6) Escalated Subtotal (Aug 1955 - June 1958)	(7)	(8) Supplemental Data	(9) Total	(10)
	Direct Losses 1/	Indirect Losses 1/	Computed by % of Physical Damages		Column 1 + 3		Column 5 x 1.085	Survey of Aug-Sept.1958	Column 6 + 8	Column 7 + 8
Residential	2,403,000		360,400		2,763,400		2,998,300	181,500		3,179,800
Commercial	251,100		92,900		344,000		373,200	126,300		449,500
Industrial	56,000	No	25,200		81,200		88,100	850,000		938,100
Utility	99,000	Indirect	9,900		108,900		118,200	-		118,200
Public	-	Losses	-		-		-	100		100
Agricultural	8,500	Listed	800		9,300		10,100	20,400		30,500
Highway	17,000		4,200		21,200		23,000	5,900		28,900
Railroad	89,000		20,500		109,500		118,800			118,800
Aid & Relief										
Red Cross	-		2/		-		-	-		-
Operation NOAH	37,100		-		37,100		40,300	-		40,300
TOTALS	2,960,700		513,900		3,474,600		3,770,000	1,184,200		$4,954,200 (Adopted Reach Total)

1/ Refer to paragraph 25 in text for explanation of original data terminology.
2/ Red Cross expenditures are included in losses computed on percentage basis for other classes

TABLE 7

BUSINESS LOSS AND COST OF EMERGENCY MEASURES **
AS A PERCENTAGE OF PHYSICAL DAMAGE

Comparison of values computed for four districts
from the flood damages of August 18-20, 1955

Class	New York	Baltimore	Washington	Philadelphia				
				Original Survey 1955	Supplemental Survey 1958			Adopted
					Port Jervis	Del. Reach C-2	Schuyl-kill Reach 5	
Residential	20 *	11	30 *	13 *				15
Commercial	33 *	43 *	23 *	48 *	35 *	35 *	40 *	37
Industrial	25 *	123 *	116 *	119 *	34 *	48 *	47 *	45
Utility	4 *	37 *	51	9 *				10
Public	50	227 *	21	44 *				34
Agricultural	10		15	5 *				10
Highway		60	60	8 *				25
Railroad	50 *	21 *	2 *	23 *				23

* Based primarily on reported damages.
** Includes Red Cross expenditures in Philadelphia and Baltimore Districts
Adopted percentages are also considered to include these expenditures.

New York District - With the exception of agricultural and public classes, the percentages are based on actual damages for 80% of the damage in the District. Agricultural and public values are based on sample determinations.

Baltimore District - Residential percentage is based on a table previously developed. The highway value is estimated. Other values are based primarily on actual reported damages.

Washington District - Residential, commercial, industrial, and railroad percentages are based primarily on reported damages. Other values are estimated.

Philadelphia District - All percentages are based on actual reported damages.

TABLE 8
DAMAGE REACHES - DELAWARE RIVER BASIN
DESCRIPTION AND AVERAGE ANNUAL DAMAGE

(Annual values are based on recurring damages as of 1958, escalated to the January 1959 price level)

MAIN STEM DELAWARE RIVER

Reach	Mile From	Mile To	Description	Aver. Annual Damage
A-1a	331.0	277.7	Hancock, N. Y. to the mouth of the Lackawaxen River	$30,100 1/
A-1b	277.7	273.0	Mouth of the Lackawaxen River to below Barryville, N. Y.	12,100 1/
A-2a	273.0	262.4	Below Barryville, N. Y. to Knights Eddy, N. Y.	13,000 1/
A-2b	262.4	253.6	Knights Eddy, N. Y. thru Port Jervis, N. Y.	210,600 1/
B-1a	253.6	226.9	Below Port Jervis, N. Y. to the mouth of Bush Kill	97,200 1/
B-1b	226.9	218.4	Mouth of Bush Kill to Tocks Is.	15,000 1/
B-2a	218.4	213.0	Tocks Is. to mouth of Brodhead Cr.	20,300 1/
B-2b	213.0	197.2	Mouth of Brodhead Cr. thru Belvidere, N. J.	191,000 1/
C-1	197.2	186.3	Below Belvidere, N. J. to Paxinosa, Pa.	185,800 1/
C-2a 2/	186.3	182.0	Paxinosa, Pa. thru Easton, Pa.	272,400 1/
Reach 2	-	-	(See Lehigh River description)	144,700 1/
C-2b	182.0	174.0	Below Easton, Pa. thru Riegelsville, Pa.	121,000 1/
D	174.0	131.5	Below Riegelsville, Pa. thru Trenton, N. J.	855,000 1/
E	131.5	116.5	Below Trenton, N. J. to the mouth of the Neshaminy Cr.	391,200 1/
F	116.5	0.0	Mouth of Neshaminy Cr. to the Capes	-
			Total	2,559,400

1/ Excludes damages eliminated by reservoir storage projects existing or under construction.
2/ Includes area previously designated as Reach 1 - Lehigh River

TABLE 8 (Continued)
DAMAGE REACHES - DELAWARE RIVER BASIN
DESCRIPTION AND AVERAGE ANNUAL DAMAGE

(Annual values are based on recurring damages as of 1958, escalated to the January 1959 price level)

MAIN STEM SCHUYLKILL RIVER

Reach	Mile From	Mile To	Description	Aver. Annual Damage
0	0.0	8.7	Mouth of Schuylkill R. to Fairmount Dam, Philadelphia, Pa.	-
1	8.7	12.8	Fairmount Dam to City Line Bridge, Philadelphia, Pa.	
2	12.8	18.4	City Line Bridge, Philadelphia, Pa. to Spring Mill Rd., Conshohocken, Pa.	$410,400 3/
3	18.4	21.3	Spring Mill Rd., Conshohocken, Pa. to Ivy Rock School	
4b	21.3	32.6	Ivy Rock School to the mouth of Perkiomen Cr.	288,500
4a	32.6	37.0	Mouth of Perkiomen Cr. to Black Rock Dam	8,200
5	37.0	64.0	Black Rock Dam to the upper limits of Birdsboro, Pa.	437,400
6b	64.0	76.1	Upper limits of Birdsboro, Pa. to the mouth of Tulpehocken Cr.	131,200
6a-2	76.1	85.6	Mouth of Tulpehocken Cr. to the mouth of Maiden Cr.	12,200
6a-1	85.6	88.2	Mouth of Maiden Cr. to the upper limits of Leesport, Pa.	3,000
7	88.2	100.6	Upper limits of Leesport, Pa. to the mouth of the Little Schuylkill River	1,400
8	100.6	129.3	Mouth of the Little Schuylkill River to just above Middleport, Pa.	3,200
			Total	1,295,500

3/ Includes reaches 1, 2 and 3.

TABLE 8 (Continued)
DAMAGE REACHES - DELAWARE RIVER BASIN
DESCRIPTION AND AVERAGE ANNUAL DAMAGE

(Annual values are based on recurring damages as of 1958, escalated to the January 1959 price level)

MAIN STEM LEHIGH RIVER

Reach	Mile From	Mile To	Description	Aver. Annual Damage
2 5/	1.0	2.6	North side of Lehigh River from suspension bridge (Jefferson St.) to the upper limits of West Easton, Pa.	$53,000 1/
3	2.6	14.0	Both sides from the upper limits of West Easton, Pa. thru Freemansburg and Bethlehem, Pa. to the upstream city limits of Bethlehem. Includes areas along the Monocacy Creek affected by backwater from the Lehigh River	635,700 1/4/
4	14.0	26.4	Both sides from the upstream city limits of Bethlehem, Pa. thru Allentown, Catasauqua, and Hokendauqua to Dam 5 (Slate Dam), near Laurys, Pa. Includes areas along Jordan Creek and Little Lehigh Creek in Allentown affected by backwater from the Lehigh River	267,000 1/4/
5	26.4	40.6	Both sides of the Lehigh River from Dam 5 thru Treichlers, Walnutport, Slatington, Palmerton, and Bowmanstown, Pa. to Dam 2 (Parryville Dam)	79,800 1/
			Total	1,035,500

1/ Excludes damages eliminated by reservoir storage projects existing or under construction.
4/ Excludes damages eliminated by local protection works existing, under construction, or authorized.
5/ Affected by backwater from Delaware River.

TABLE 8 (Continued)
DAMAGE REACHES - DELAWARE RIVER BASIN
DESCRIPTION AND AVERAGE ANNUAL DAMAGE

(Annual values are based on recurring damages as of 1958, escalated to the January 1959 price level)

LACKAWAXEN RIVER AND DYBERRY CREEK

Zone	Mile From	Mile To	Description	Aver. Annual Damage
A	22.4	23.2	Honesdale, Pa., below 4th St.	$11,200 1/
B	23.2	24.6	Honesdale, Pa., between 4th St., mouth of Dyberry Cr. and lower limits of Zone E	50,600 1/
C	0.0	0.7	Dyberry Cr. from mouth to Henwood Ave. Bridge, Honesdale, Pa.	13,600 1/
D	0.7	10.8	Dyberry Creek, Henwood Ave. Bridge to the Dyberry dam site	1,200 1/
E	24.6	25.0	Honesdale, Pa., Maple Ave. section	2,400 1/
F	13.0	14.1	Hawley, Pa., along the Lackawaxen River	9,600 1/
G 6/	0.0	0.3	Hawley, Pa., along Middle Creek	6,200 1/
H	14.1 25.0	22.4 28.1	Rural areas between Hawley, Pa., and Prompton dam site	17,900 1/
Below Hawley	0.0	13.0	Mouth of Lackawaxen River to just below Hawley, Pa.	31,300 1/
			Total	144,000

1/ Excludes damages eliminated by reservoir storage projects existing or under construction.
6/ Affected by backwater from Lackawaxen River.

TABLE 8 (Continued)
DAMAGE REACHES - DELAWARE RIVER BASIN
DESCRIPTION AND AVERAGE ANNUAL DAMAGE

(Annual values are based on recurring damages as of 1958, escalated to the January 1959 price level)

TRIBUTARY REACHES

Stream	Mile From	Mile To	Description	Aver. Annual Damage
Shohola Cr.	0.0	8.4	Mouth to Shohola dam site at Shohola Falls, Pa.	$11,700
Neversink R. (I) 8/	0.0	9.4	Mouth to the mouth of Basher Kill	175,600 1/
Neversink R. (II) 8/	9.4	26.2	Mouth of Basher Kill to Bridgeville dam site just above Bridgeville, N. Y.	1,100 1/
Bush Kill	0.0	14.2	Mouth to Girard dam site, near Camp Girard, Pa.	20,300
Brodhead (I)	0.0	4.0	Mouth to mouth of McMichaels Cr., E. Stroudsburg, Pa.	33,000
Brodhead (II)	4.0	12.6	Thru Stroudsburg, Pa. and E. Stroudsburg, Pa. to Pine Mtn. dam site, approx. 3.4 mi. above Analomink, Pa.	91,300 4/
McMichaels Cr. (I)	0.0	1.0	Mouth to mouth of Pocono Cr., Stroudsburg, Pa.	4,200 4/
McMichaels Cr. (II)	1.0	4.8	Mouth of Pocono Cr. to McMichaels dam site 5 mi. SW of Stroudsburg, Pa.	200
Pocono Cr.	0.0	2.9	Mouth to Bartonsville dam site, Pocono, Pa.	3,300 4/
Paulins Kill	0.0	11.8	Mouth to Paulina dam site, above Blairstown, N. J.	27,800
Beaver Cr.	0.0	3.8	Mouth to Sarepta dam site, above Sarepta, N. J.	7/
Pequest R.	0.0	8.2	Mouth to Pequest dam site, above Pequest, N. J.	7/
Bushkill Cr.	0.9	9.8	Just below Lafayette College to Belfast dam site at Belfast Junction, Pa.	117,800
Pohopocc Cr. (Lehigh R. Basin)	0.0	4.6	Mouth to Beltzville dam site .6 mi. above Big Creek, Pa.	3,500

1/ Excludes damages eliminated by reservoir storage projects existing or under construction.
4/ Excludes damages eliminated by local protection works existing or under construction.
7/ No significant flood damage reported.
8/ (I) and (II) refer to individual reaches on the same stream.

TABLE 8

TRIBUTARY REACHES (Continued)

Stream	Mile From	Mile To	Description	Aver. Annual Damage
Aquashicola Cr. (Lehigh R. Basin)	0.5	4.2	Palmerton, Pa. to Aquashicola dam site at Walkton, Pa.	$136,800
Jordan Cr. (Lehigh R. Basin)	1.1	17.2	Route 22 highway bridge, Allentown, Pa. to Trexler dam site below Weidasville, Pa.	8,000
Pohatcong Cr.	0.0	18.8	Mouth to Washington dam site near Washington, N. J.	7/
Musconetcong R. (I)8/	0.0	16.5	Mouth to New Hampton dam site, near New Hampton, N.J.	11,000
Musconetcong R. (II)8/	16.5	33.4	New Hampton dam site to Hackettstown dam site near Saxton Falls, N. J.	6,800
Tohickon Cr.	0.0	10.6	Mouth to Tohickon dam site, near Tohickon, Pa.	1,000
Crosswicks Cr.	0.0	11.8	Mouth to Crosswicks dam site, 1.3 mi. below gaging station at Extonville, N. J.	1,100
Neshaminy Cr. (I)	0.0	20.2	Mouth to Newtown dam site above Newtown, Pa.	46,700
Neshaminy Cr. (II)	20.2	41.3	Newtown dam site to just above Chalfont, Pa.	8,500
Rancocas Cr. (I)	0.0	13.9	Confluence of N.& S.Br. Rancocas Cr. to Birmingham dam site below Pemberton,N.J. on N.Br. Rancocas Cr.	2,100 4/
Rancocas Cr. (II)	0.0	15.4	Mouth of Rancocas Cr. to Eayrestown dam site below Eayrestown, N.J. on S.Br. Rancocas Cr.	7,400
Maiden Cr. (Schuylkill R. Basin)	0.0	9.5	Mouth to Maiden Creek dam site near Moselem, Pa.	1,400
Tulpehocken Cr. (Schuylkill R. Basin)	0.0	14.4	Mouth to Bernville dam site near Bernville, Pa.	5,100
Manatawney Cr. (Schuylkill R. Basin)	0.0	8.9	Mouth to Fancy Hill dam site near Earlville, Pa.	3,400
French Cr. (Schuylkill R. Basin)	0.0	9.2	Mouth to French Creek dam site, .7 miles above Sheeder, Pa.	4,300

4/ Excludes damages eliminated by local protection works existing or under construction
7/ No significant flood damage reported.
8/ (I) and (II) refer to individual reaches on the same stream.

TABLE 8

TRIBUTARY REACHES (Continued)

Stream	Mile From	Mile To	Description	Aver. Annual Damage
Perkiomen Cr. (I) 8/ (Schuylkill R. Basin)	0.0	3.0	Mouth to mouth of Skippack Cr.	$2,400
Perkiomen Cr. (II) 8/ (Schuylkill R. Basin)	3.0	10.9	Mouth of Skippack Creek to Spring Mtn. dam site near Schwenksville, Pa.	37,400
Brandywine Cr. (I)	0.0	8.7	Mouth to New Castle dam site, 1.7 mi. above Rockland, Del.	49,300
Brandywine Cr. (II)	8.7	19.7	New Castle dam site to the confluence of the E.& W. Br. Brandywine Cr. near Lenape, Pa.	45,200
E.Br. Brandywine Cr.	0.0	13.2	Confluence of the E.& W. Br. to Lyndell, Pa.	48,200
W.Br. Brandywine Cr.	0.0	18.3	Confluence of the E.& W. Br. to Siousca, Pa.	145,800
White Clay Cr.	2.5	11.2	Confluence of Red Clay Cr. & White Clay Cr. to Newark dam site near Newark, Del.	1,800
Christina R.	10.6	17.4	Confluence of White Clay Cr. & Christina R. to Christiana dam site near Christiana, Del.	——— 7/
			Total	1,063,500

7/ No significant flood damage reported.
8/ (I) and (II) refer to individual reaches on the same stream.

TABLE 8 (Continued)
DAMAGE REACHES - DELAWARE RIVER BASIN
DESCRIPTION AND AVERAGE ANNUAL DAMAGE

(Annual values are based on recurring damages as of 1958, escalated to the January 1959 price level)

SUMMARY OF AVERAGE ANNUAL DAMAGES IN THE REACHES STUDIED

LEHIGH RIVER BASIN	$1,183,800
SCHUYLKILL RIVER BASIN	1,349,500
LACKAWAXEN RIVER BASIN	144,000
DELAWARE BASIN (excluding above)	3,420,600
DELAWARE RIVER BASIN - GRAND TOTAL	6,097,900

CORPS OF ENGINEERS

2

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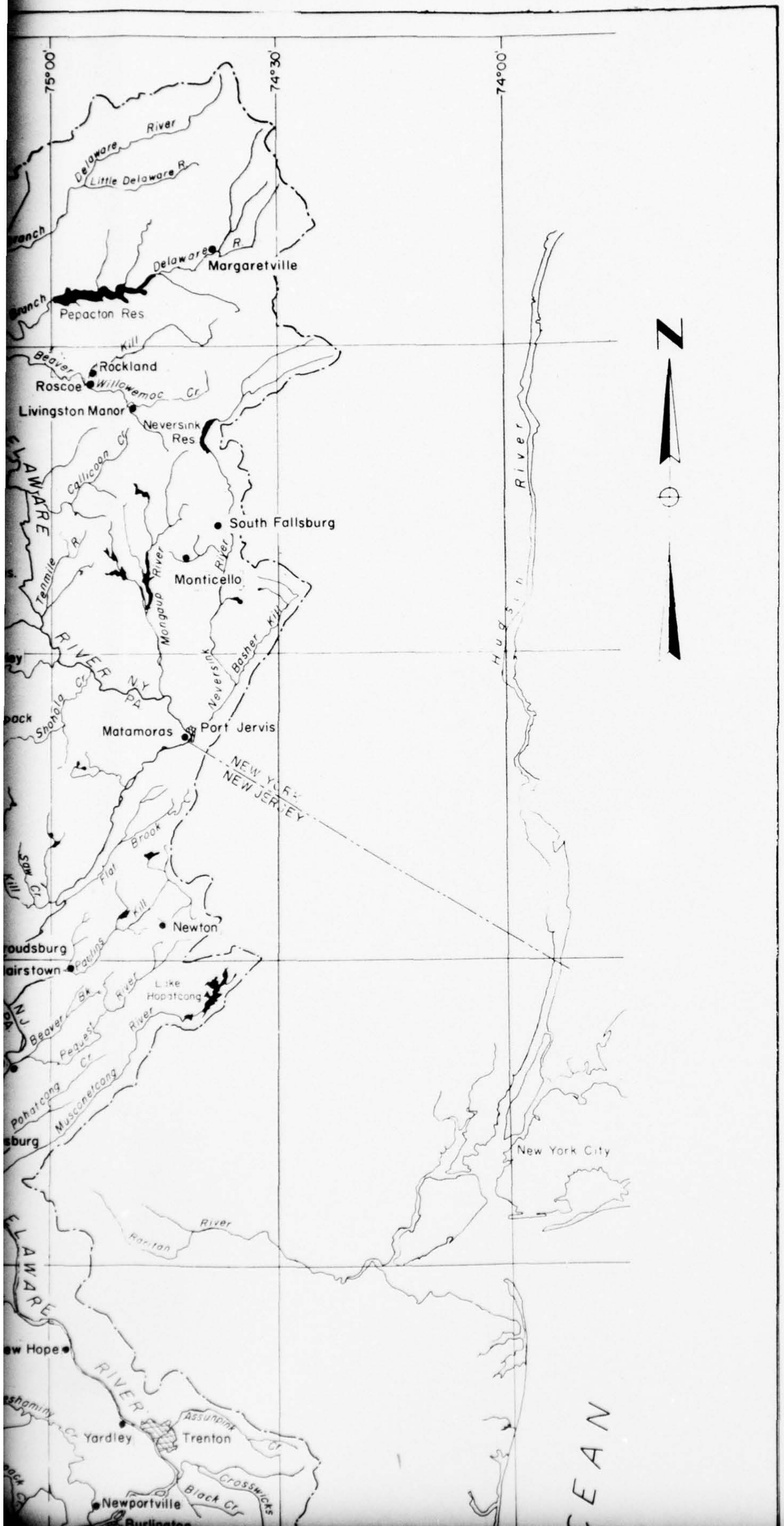
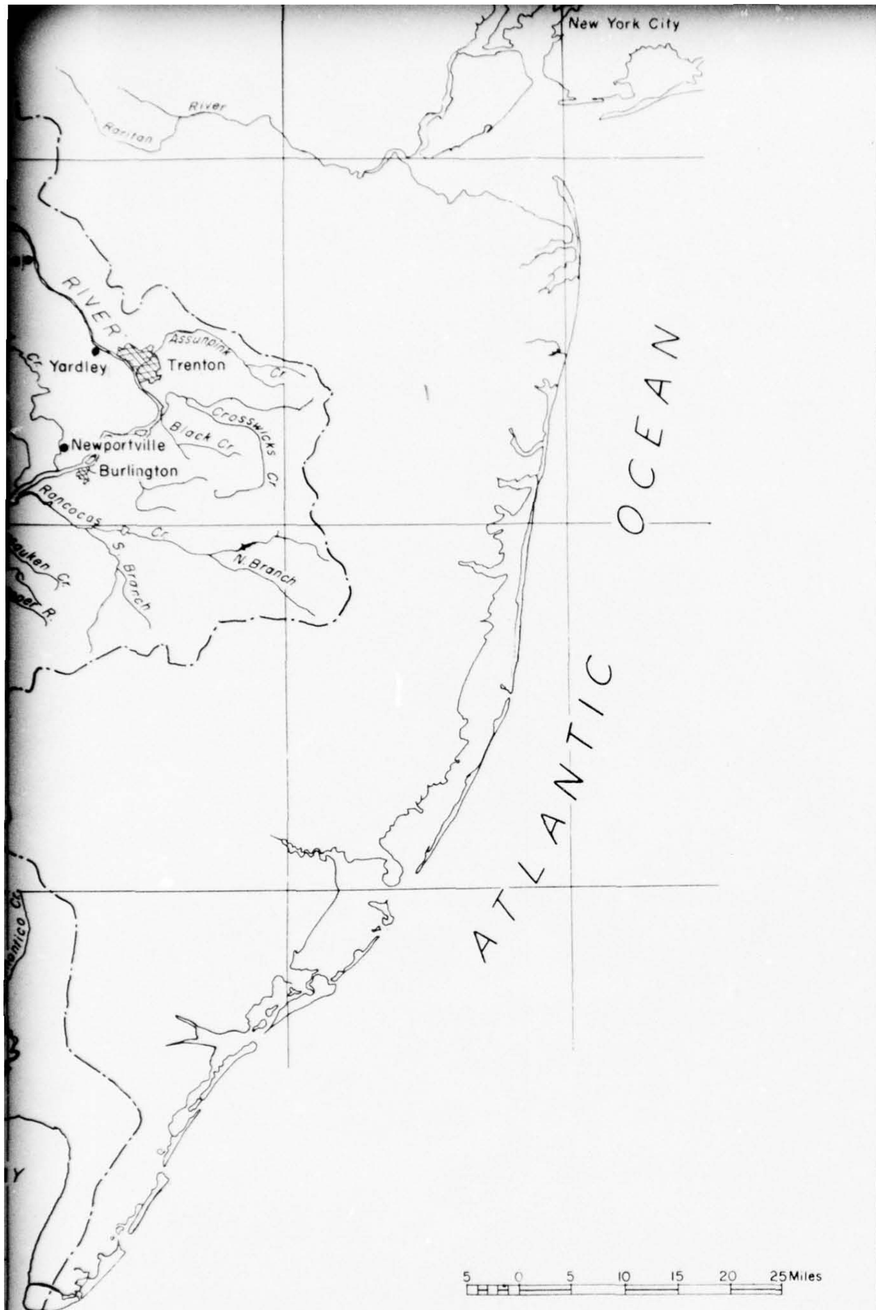

75°00'
74°30'
74°00'
Delaware River
Little Delaware R.
Branch
Delaware R.
Margaretville
Branch
Pepacton Res
Beaver Kill
Rockland
Roscoe
Willowemoc Cr.
Livingston Manor
Neversink Res
DELAWARE
Callicoon Cr.
South Fallsburg
Tenmile R.
Mongaup River
Neversink River
Monticello
Basher Kill
RIVER
NY
PA
Shohola Cr.
Matamoras
Port Jervis
NEW YORK
NEW JERSEY
Flat Brook
Saw Cr.
Kill
Newton
Paulins Kill
Blairstown
Lake Hopatcong
Beaver Bk.
Pequest River
River
NJ
PA
Pohatcong Cr.
Musconetcong
Hudson River
New York City
Raritan River
DELAWARE
New Hope
RIVER
Yardley
Assunpink Cr.
Trenton
Crosswicks
Black Cr.
Newportville
Burlington
N
OCEAN

3

Easton
Catasauqua
Bethlehem
Freemansburg
Allentown
Riegelsville
Port Clinton
Little
Maiden
Creek
Jordan
Cr
Sacony
Cr
L. Lehigh Cr
Saucon
Kutztown
DELAWARE
Raritan
River
40°30'
Tohickon
Cr
Tulpehocken
Cr
Reading
Manacacy Cr
Manatawny Cr
Perkiomen Cr
Northeast Br
New Hope
Chalfont
Neshaminy
Cr
RIVER
Pottstown
Birdsboro
Schuylkill
Skippack Cr
Yardley
Assunpink
Trenton
Cr
French
Cr
Pennypack Cr
Norristown
River
Newportville
Burlington
Black Cr
Crosswicks Cr
East Branch
Downingtown
40°00'
Coatesville
West Branch
Brandywine
Ridley
Crum
Cr
Chester
Cr
Philadelphia
Rancocas
Cr
Pensauken Cr
S. Branch
N. Branch
Cooper R.
Susquehanna
White
Clay
Red Clay Cr
PA
DEL
Big Timber Cr
Woodbury Cr
DEL
NJ
Raccoon
Cr
Oldmans
Cr
Wilmington
PENNSYLVANIA
MARYLAND
Clay
Cr
R
River
Christina
Salem
Cr
Salem R
C&D Canal
Alloways
Cr
39°30'
River
River
Maurice
Manantico Cr
Cohansey
Mouth of River
Chesapeake Bay
Smyrna
R
NJ
DEL
MD
DEL
St Jones
R
Little R
DELAWARE BAY
Murderkill R
39°00'
Mispillion R
Mouth of bay
Broadkill Cr
Lewes & Rehoboth Canal
76°30'
76°00'
75°30'



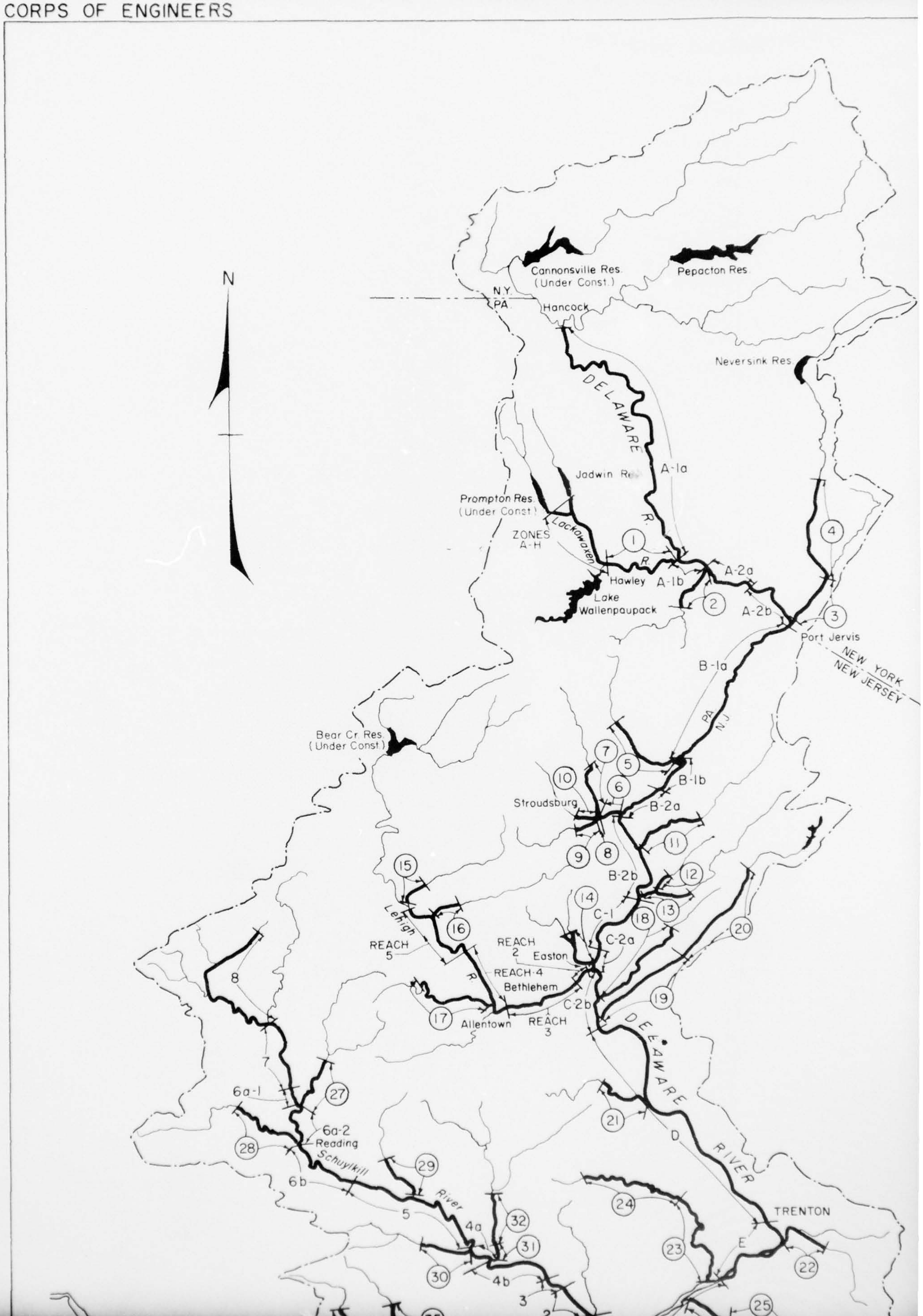
REVIEW REPORT

DELAWARE RIVER BASIN

DAMAGE CENTERS

In 1 Sheet	Scale as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	9 NOV. 1959
Drawer No. 228	File No. 29126

PLATE NO. 1


N
Cannonsville Res.
(Under Const.)
Pepacton Res.
N.Y.
PA.
Hancock
Neversink Res.
DELAWARE
A-1a
Jadwin Res.
R.
Prompton Res.
(Under Const.)
Lackawaxen
ZONES
A-H
R.
Hawley
A-1b
A-2a
Lake
Wallenpaupack
A-2b
Port Jervis
NEW YORK
NEW JERSEY
B-1a
PA
NJ
Bear Cr. Res.
(Under Const.)
B-1b
Stroudsburg
B-2a
B-2b
Lehigh
REACH
5
REACH
2
Easton
C-1
C-2a
REACH-4
Bethlehem
C-2b
Allentown
REACH
3
DELAWARE
RIVER
D
6a-1
6a-2
Reading
Schuylkill
River
6b
5
4a
4b
3
2
TRENTON
E
1
2
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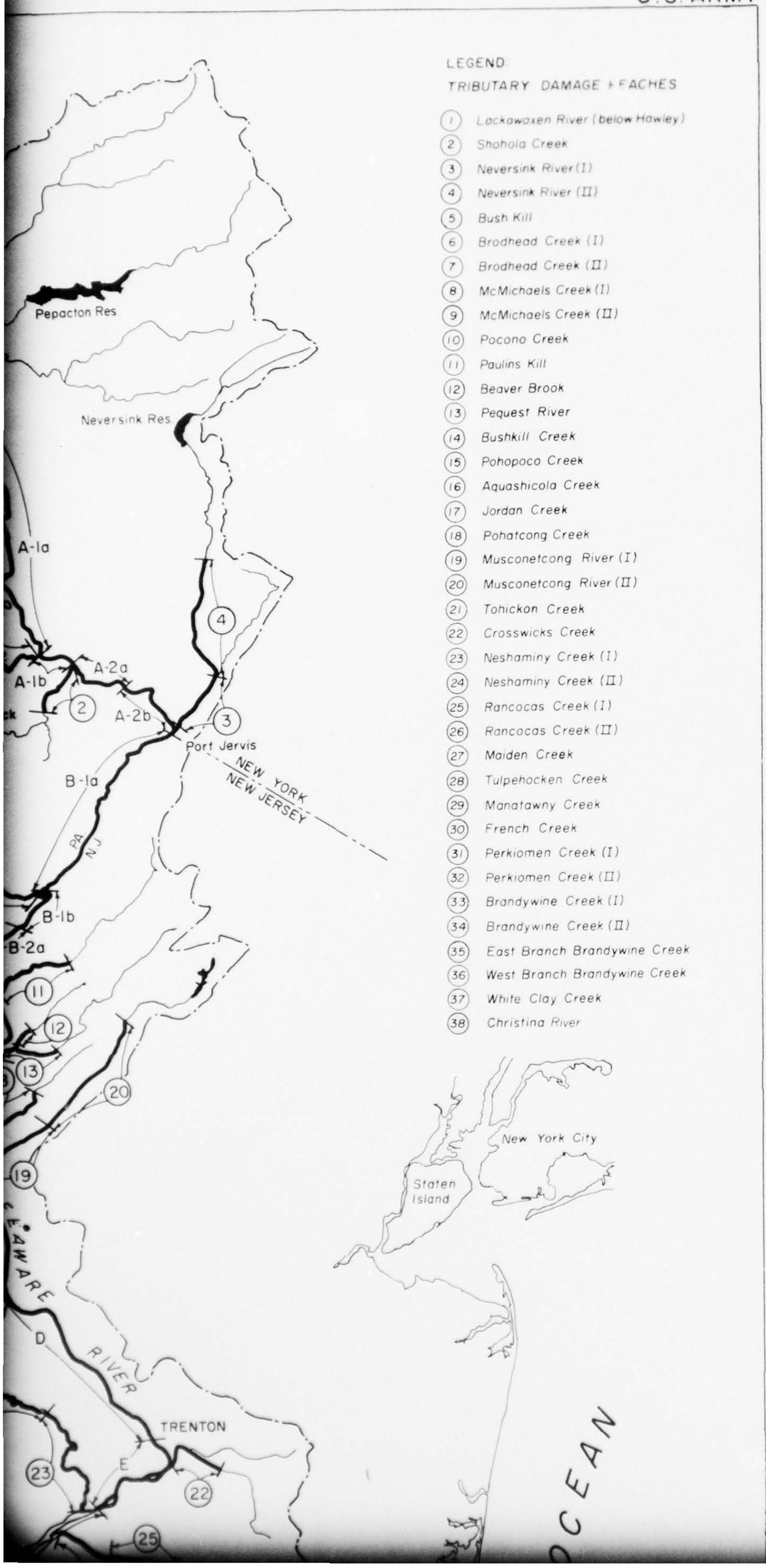
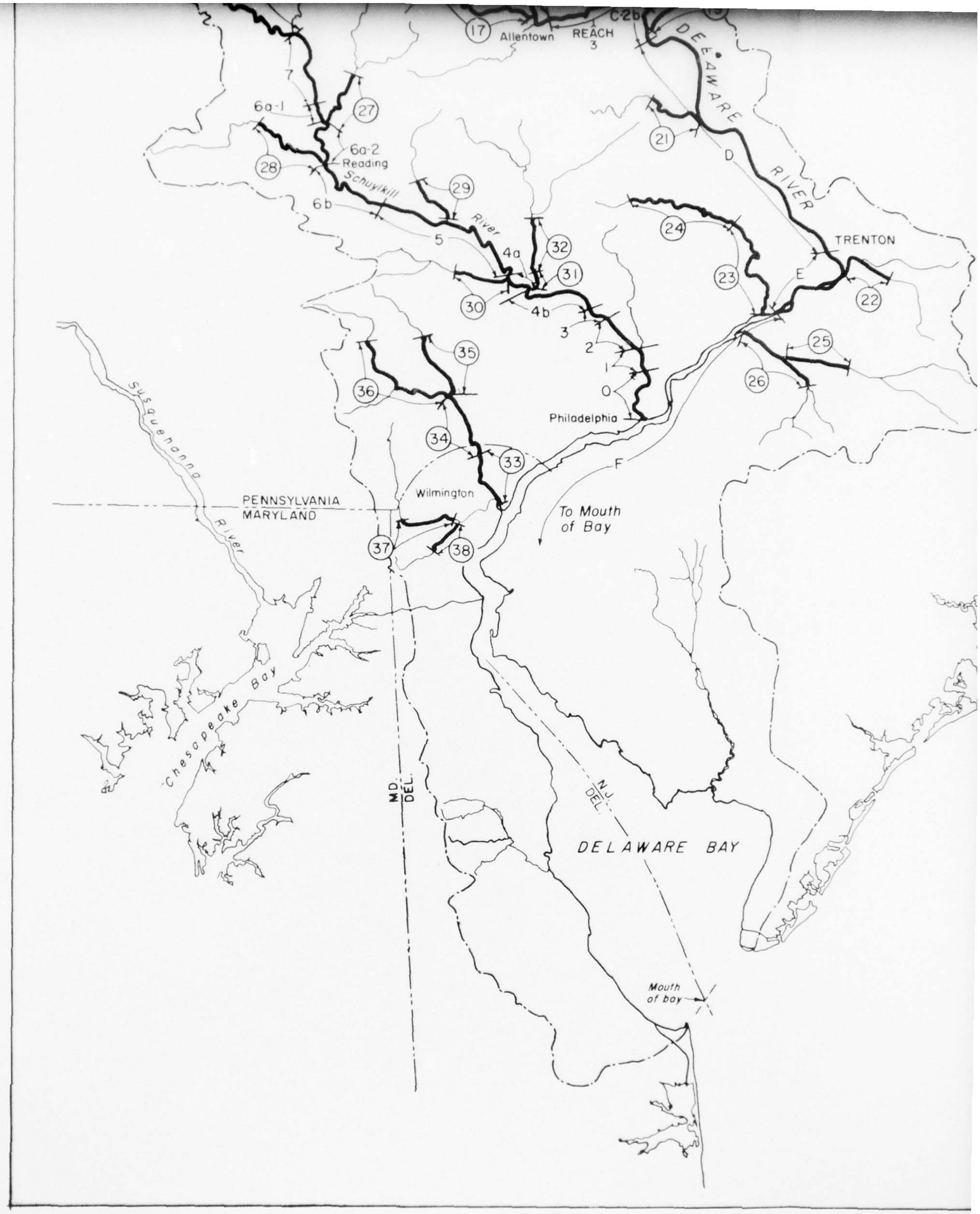
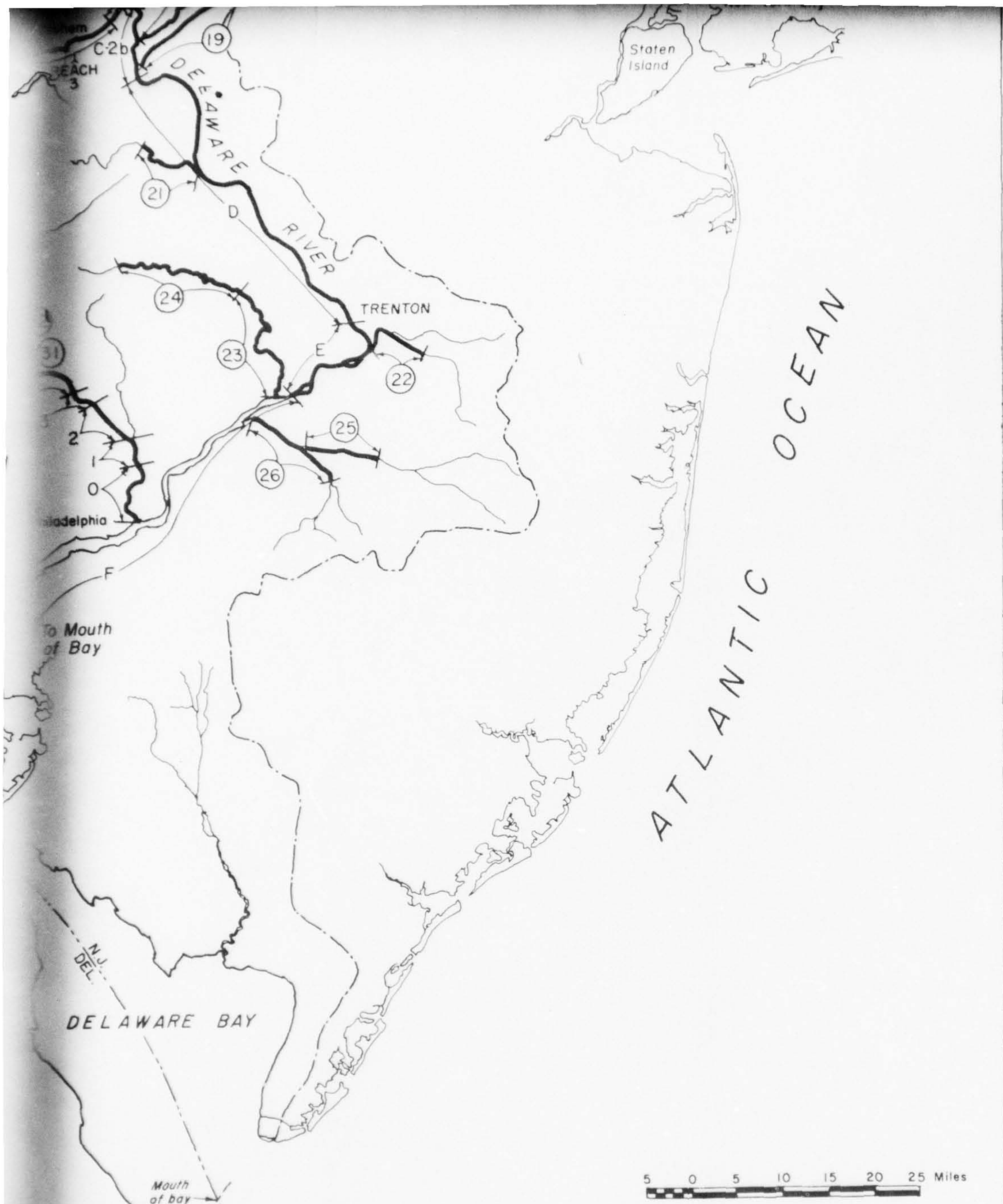

LEGEND
TRIBUTARY DAMAGE REACHES
1 Lackawaxen River (below Hawley)
2 Shohola Creek
3 Neversink River (I)
4 Neversink River (II)
5 Bush Kill
6 Brodhead Creek (I)
7 Brodhead Creek (II)
8 McMichaels Creek (I)
9 McMichaels Creek (II)
10 Pocono Creek
11 Paulins Kill
12 Beaver Brook
13 Pequest River
14 Bushkill Creek
15 Pohopoco Creek
16 Aquashicola Creek
17 Jordan Creek
18 Pohatcong Creek
19 Musconetcong River (I)
20 Musconetcong River (II)
21 Tohickon Creek
22 Crosswicks Creek
23 Neshaminy Creek (I)
24 Neshaminy Creek (II)
25 Rancocas Creek (I)
26 Rancocas Creek (II)
27 Maiden Creek
28 Tulpehocken Creek
29 Manatawny Creek
30 French Creek
31 Perkiomen Creek (I)
32 Perkiomen Creek (II)
33 Brandywine Creek (I)
34 Brandywine Creek (II)
35 East Branch Brandywine Creek
36 West Branch Brandywine Creek
37 White Clay Creek
38 Christina River
Pepacton Res
Neversink Res
A-1a
A-1b
A-2a
A-2b
B-1a
B-1b
B-2a
Port Jervis
NEW YORK
NEW JERSEY
PA
NJ
New York City
Staten Island
DELAWARE RIVER
D
E
TRENTON
OCEAN



17
Allentown
REACH
3
C-2b
DELAWARE
RIVER
7
6a-1
27
6a-2
Reading
28
Schuylkill
River
29
6b
21
D
24
5
4a
32
31
TRENTON
23
E
22
30
4b
3
2
1
0
25
26
35
36
Philadelphia
34
33
Wilmington
F
To Mouth
of Bay
Susquehanna
River
PENNSYLVANIA
MARYLAND
37
38
Chesapeake Bay
MD.
DEL.
N.J.
DEL.
DELAWARE BAY
Mouth
of bay



REVIEW REPORT
DELAWARE RIVER BASIN

DAMAGE REACHES

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
6 Nov 1959

Drawer No. 228

File No. 29127

PLATE NO. 2

4

AD-A043 793 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 8/6

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)

DEC 60

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5 OF 6

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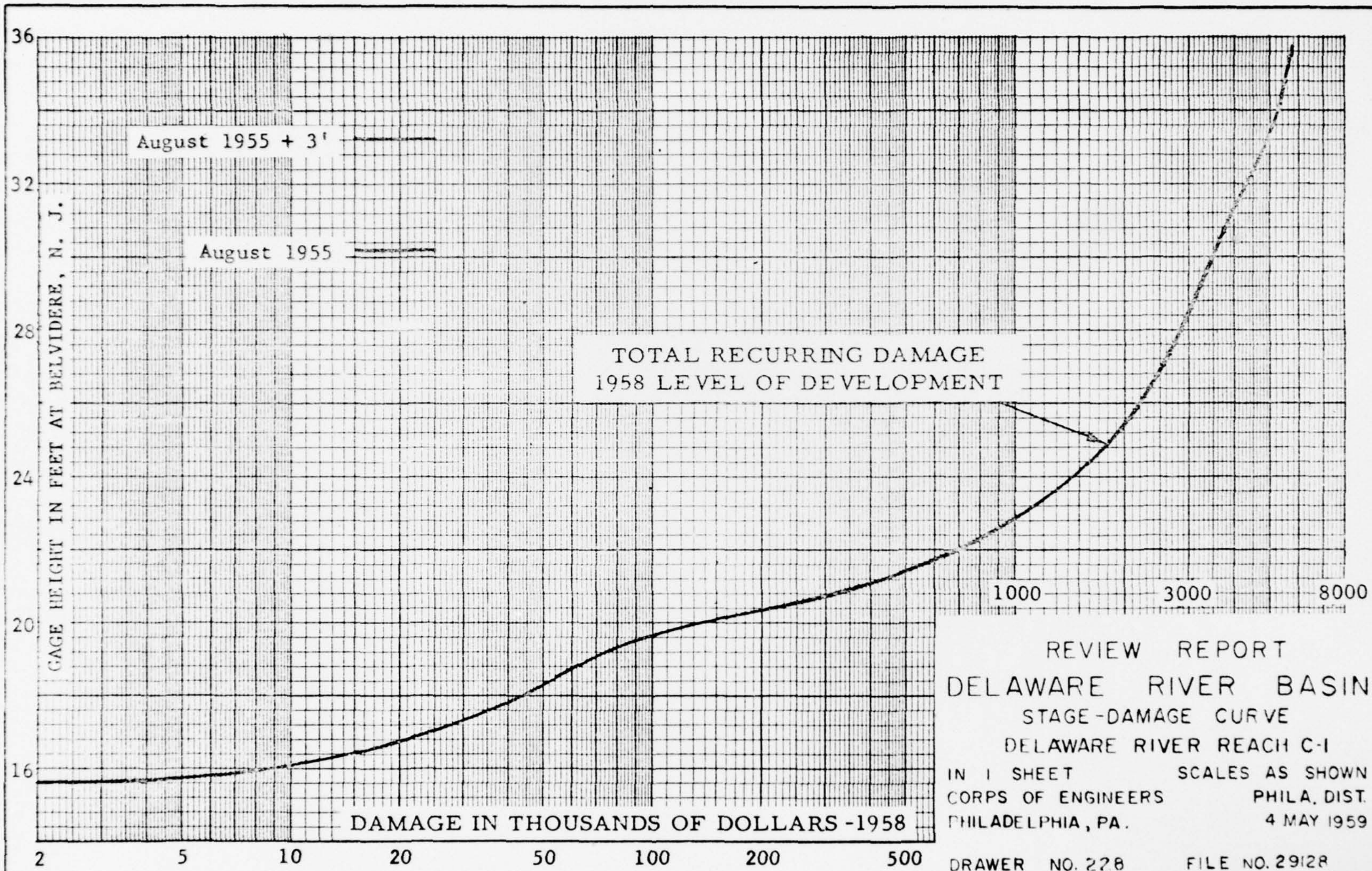
CORPS OF ENGINEERS U.S. ARMY



REVIEW REPORT
DELAWARE RIVER BASIN
STAGE-DAMAGE CURVE
DELAWARE RIVER REACH C-I

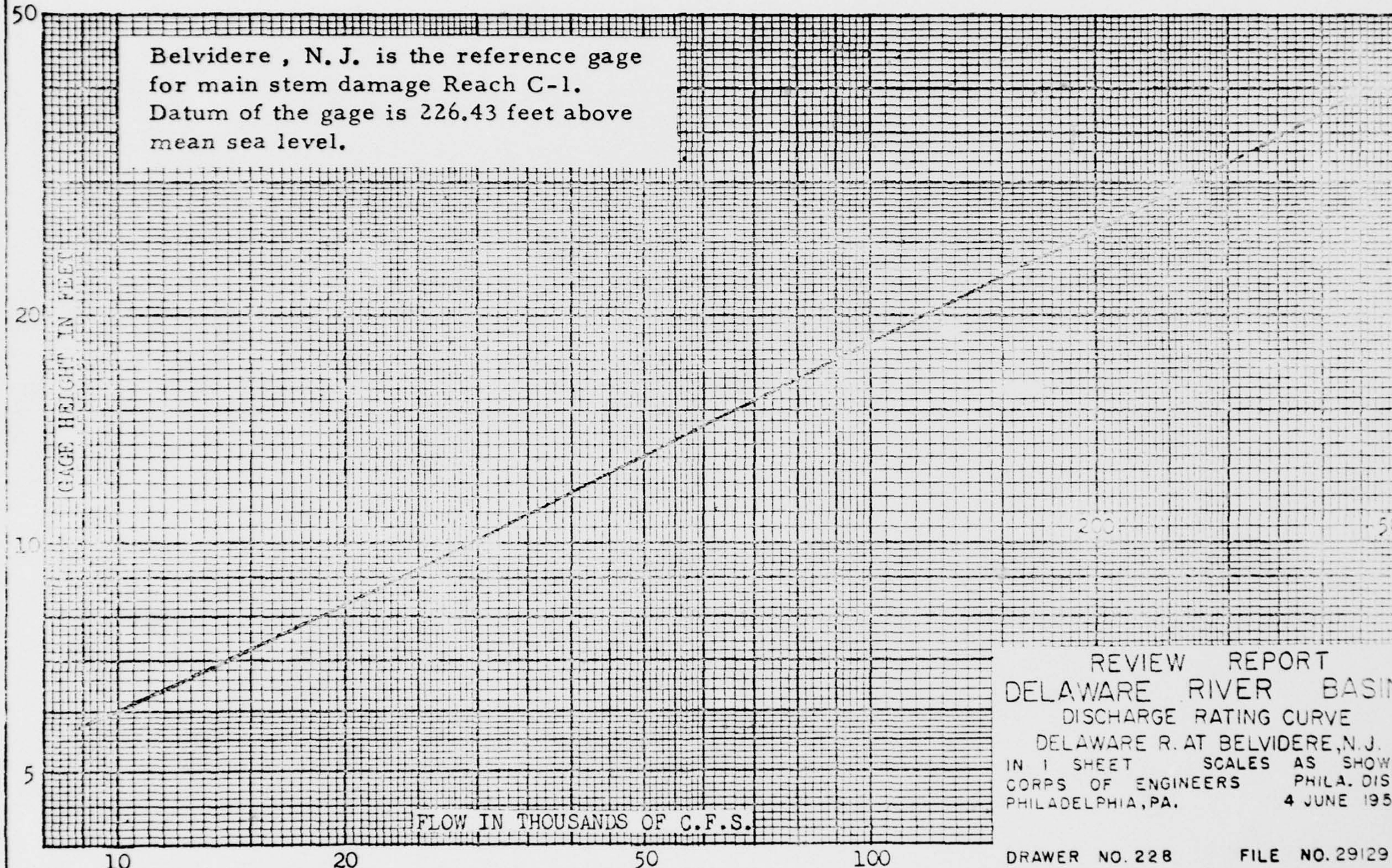
IN I SHEET SCALES AS SHOWN
CORPS OF ENGINEERS PHILA. DIST.
PHILADELPHIA, PA. 4 MAY 1959

DRAWER NO. 228 FILE NO. 29128

PLATE NO 3

CORPS OF ENGINEERS

U.S. ARMY



REVIEW REPORT
DELAWARE RIVER BASIN
DISCHARGE RATING CURVE
DELAWARE R. AT BELVIDERE, N.J.

IN 1 SHEET SCALES AS SHOWN
CORPS OF ENGINEERS PHILA. DIST.
PHILADELPHIA, PA. 4 JUNE 1959

DRAWER NO. 228 FILE NO. 29129

PLATE NO. 4

CORPS OF ENGINEERS U. S. ARMY

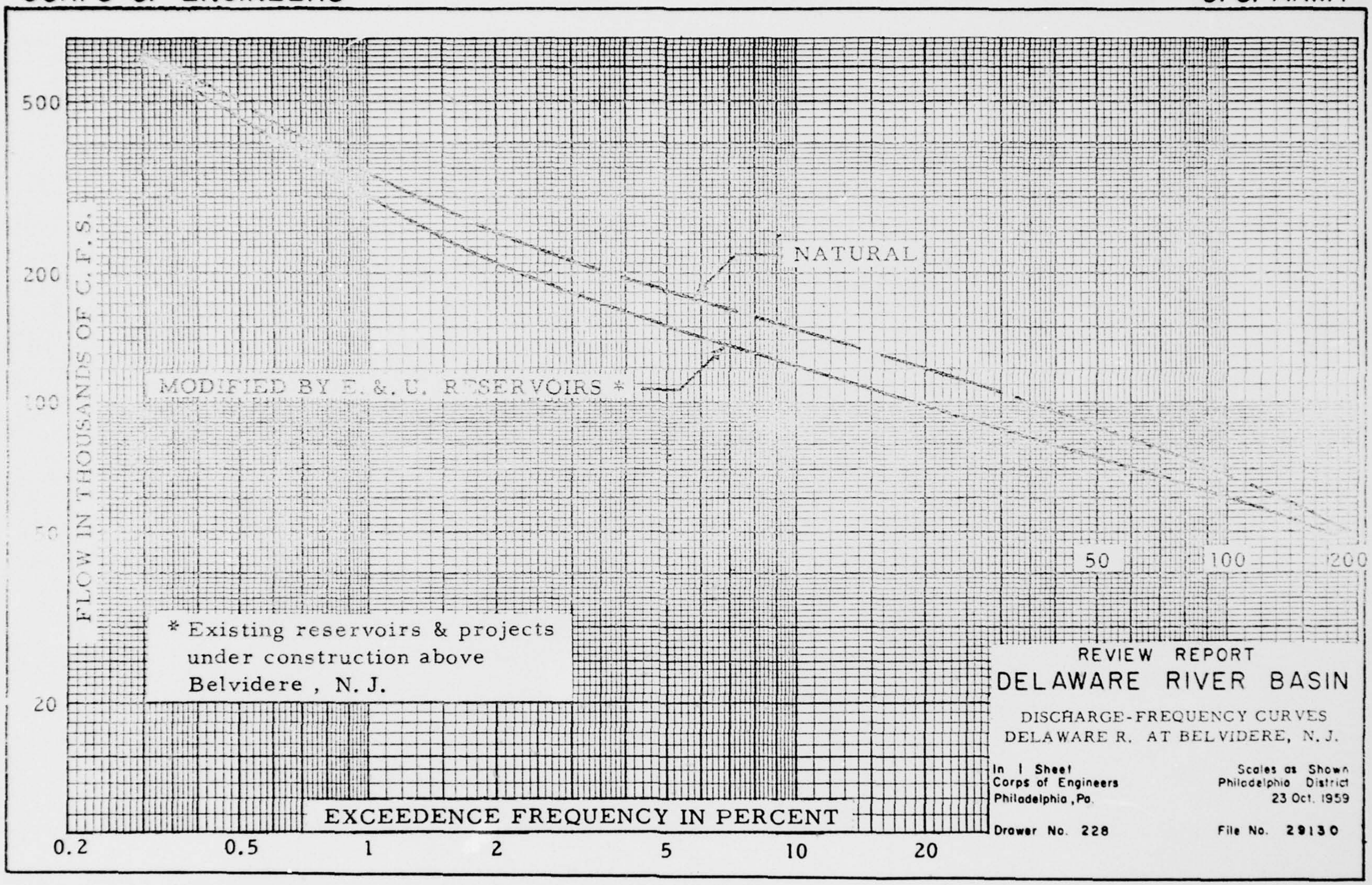
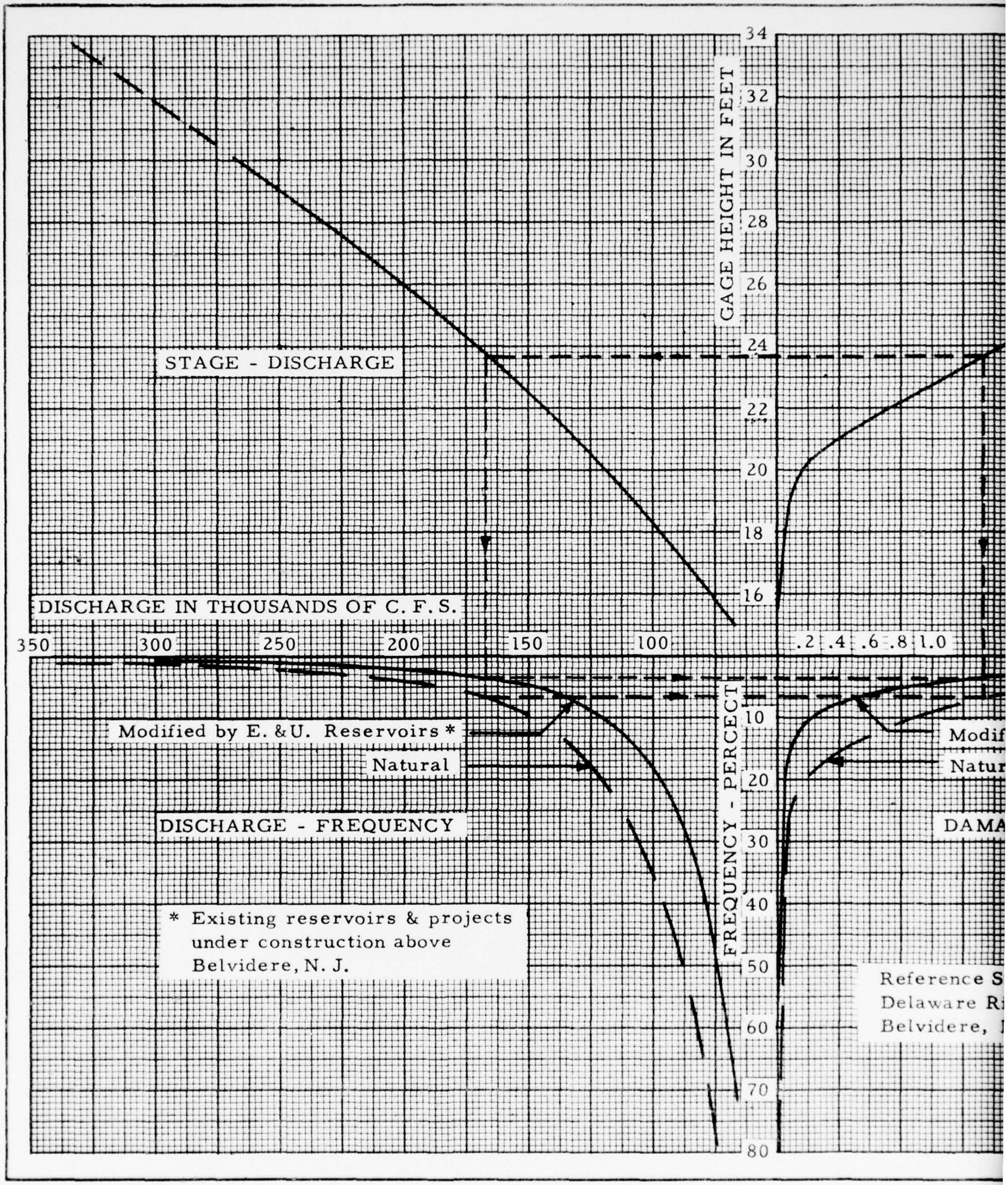


PLATE NO. 5



STAGE - DISCHARGE
GAGE HEIGHT IN FEET
34
32
30
28
26
24
22
20
18
16
DISCHARGE IN THOUSANDS OF C. F. S.
350
300
250
200
150
100
.2
.4
.6
.8
1.0
Modified by E. &U. Reservoirs *
Natural
DISCHARGE - FREQUENCY
FREQUENCY - PERCECT
10
20
30
40
50
60
70
80
* Existing reservoirs & projects under construction above Belvidere, N. J.
Modif
Natur
DAMA
Reference S
Delaware R
Belvidere,

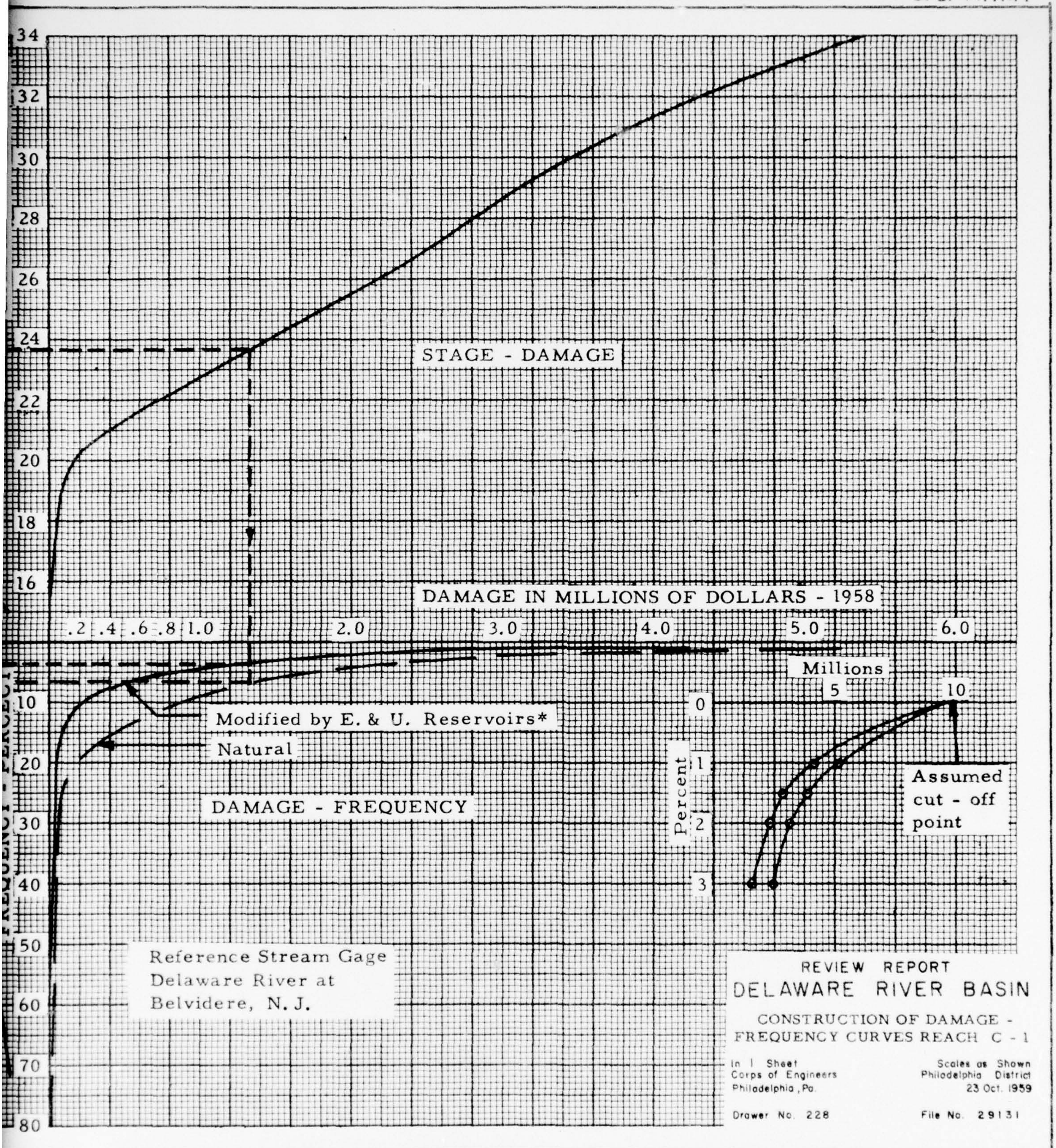
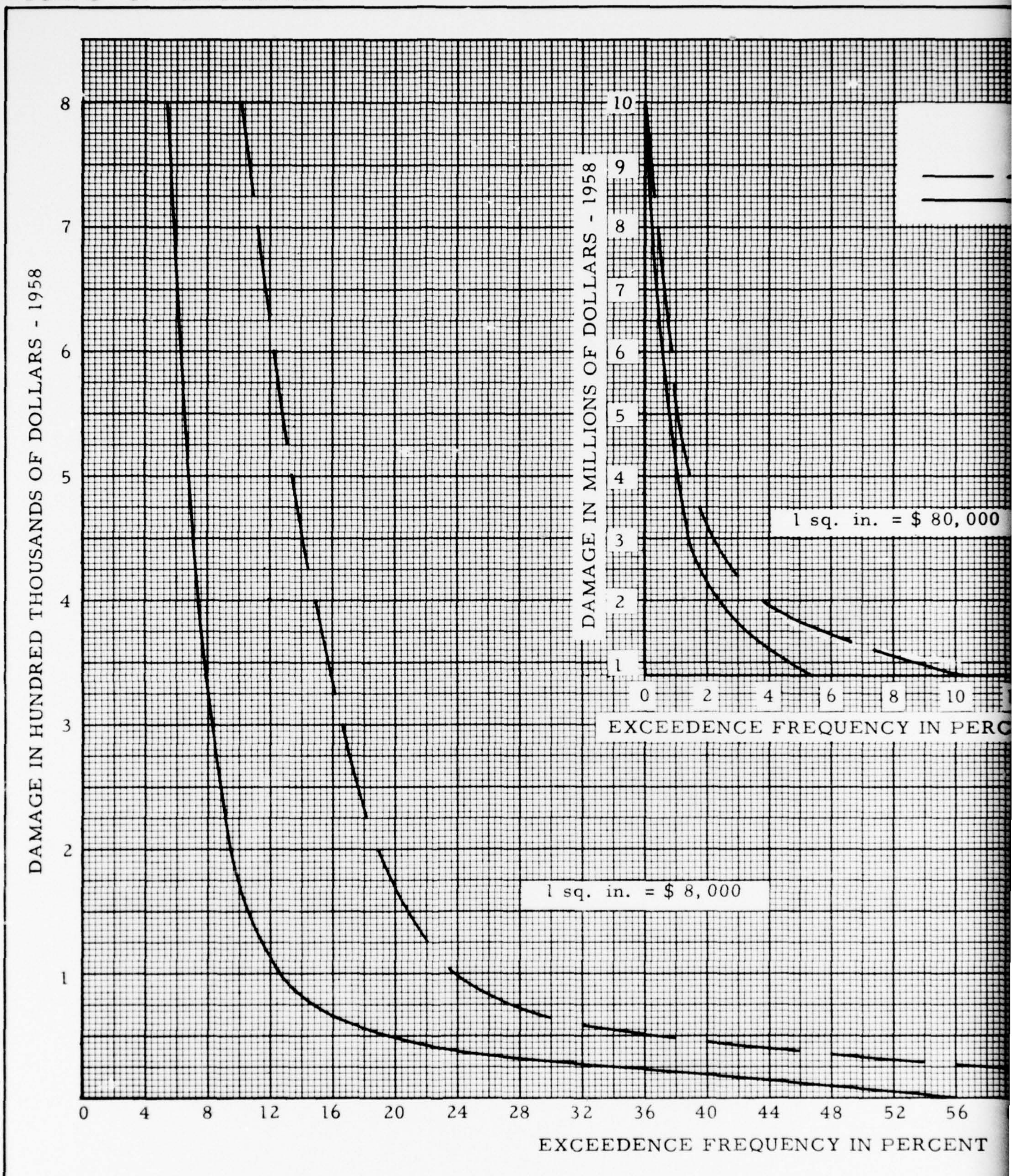
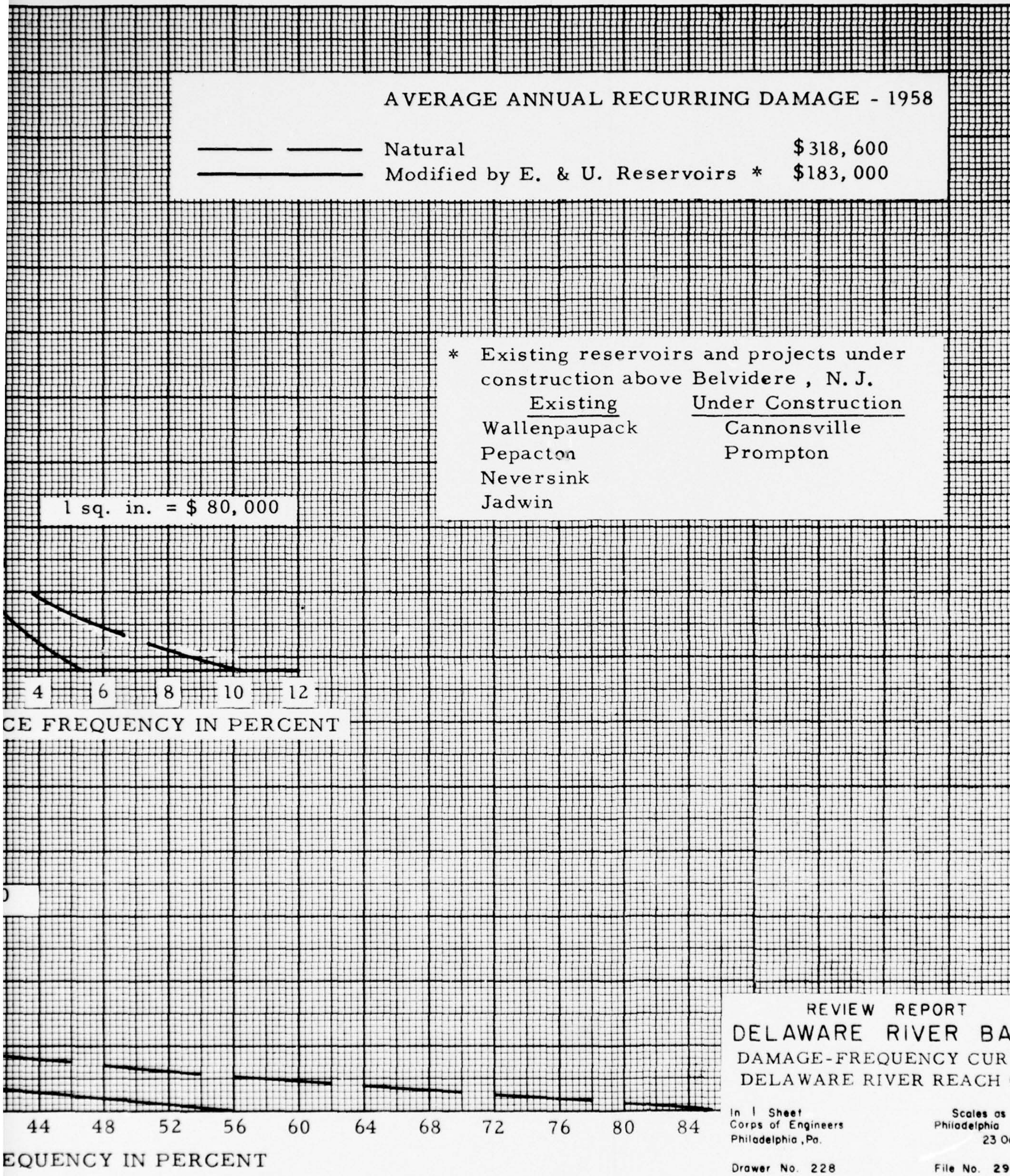

STAGE - DAMAGE
DAMAGE IN MILLIONS OF DOLLARS - 1958
.2 .4 .6 .8 1.0 2.0 3.0 4.0 5.0 6.0
Millions
5 10
0 1 2 3
Percent
Modified by E. & U. Reservoirs*
Natural
DAMAGE - FREQUENCY
Assumed cut - off point
34 32 30 28 26 24 22 20 18 16
10 20 30 40 50 60 70 80
Reference Stream Gage
Delaware River at
Belvidere, N. J.
REVIEW REPORT
DELAWARE RIVER BASIN
CONSTRUCTION OF DAMAGE -
FREQUENCY CURVES REACH C - 1
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.
Scales as Shown
Philadelphia District
23 Oct. 1959
Drawer No. 228
File No. 29131

PLATE NO. 6

CORPS OF ENGINEERS



U.S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

DAMAGE-FREQUENCY CURVES

DELAWARE RIVER REACH C-1

In 1 Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	23 Oct. 1959
Drawer No. 228	File No. 29132

PLATE NO. 7

Figure 1. - Aerial view of Delaware, Lackawanna & Western Railroad tracks along Brodhead Creek - Flood of August 1955.

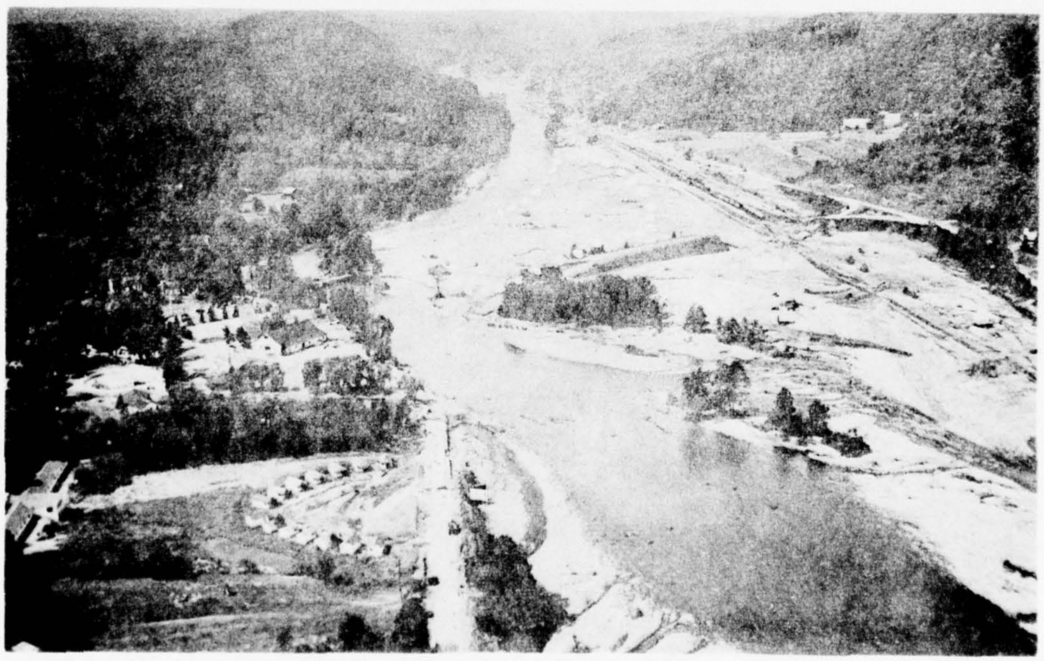


Figure 2- Aerial view of Route 90 along Broadhead Creek. Area outlined in dots was site of Camp Davis, a children's summer camp, which was washed away by the Flood of August 1955.

PLATE 8

Figure 1. - View of Bushkill Creek during flood of August 1955 - Houses flooded in vicinity of Easton, Pa.

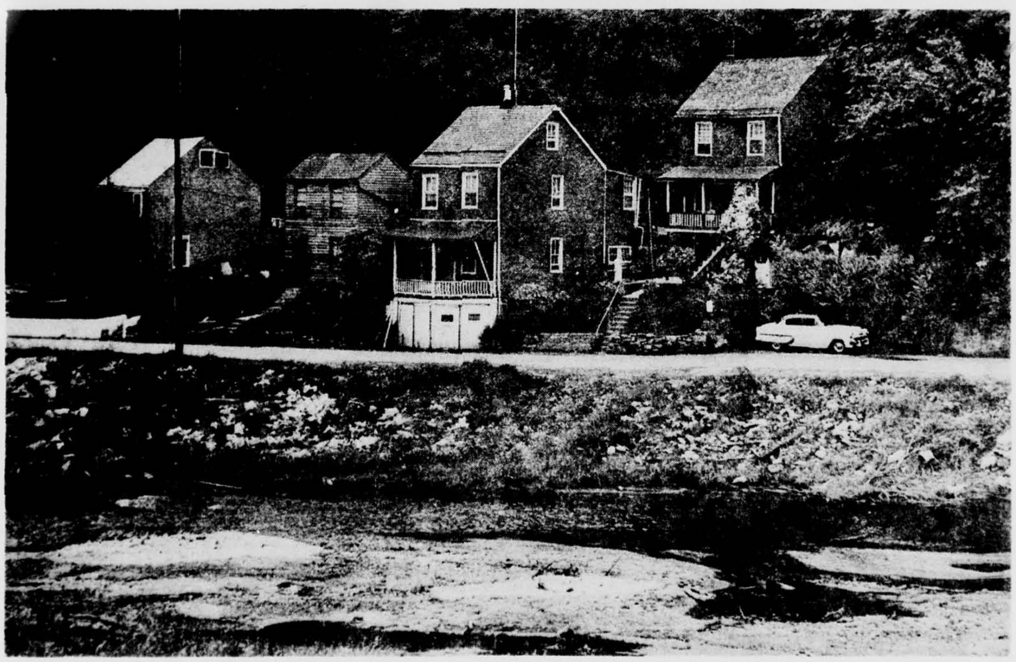


Figure 2. View of Bushkill Creek after flood of August 1955 - Same houses as in figure 1 above.

PLATE 9

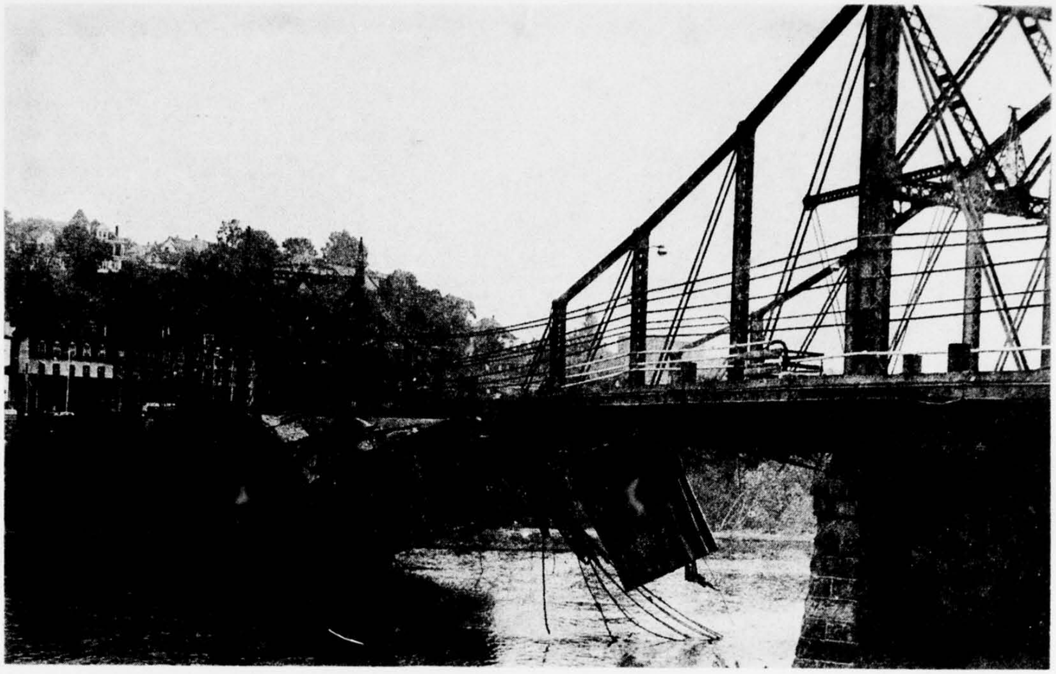


Figure 1. - Delaware River at Easton, Pa. - Phillipsburg, N. J. - Highway bridge destroyed by flood of August 1955.

Figure 2. - View in vicinity of Second Avenue Bridge (Hill to Hill Bridge) Bethehem, Pa. - Showing high watermark of flood of August 1955.

PLATE 10

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN

APPENDIX E

NAVIGATION

PREPARED BY THE
U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
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PHILADELPHIA, PA.

APPENDIX E - NAVIGATION

TABLE OF CONTENTS

APPENDIX E - NAVIGATION

SECTION I - PURPOSE AND EXTENT OF STUDY

1-01. The objective of the studies covered by this appendix is to determine the need for improvements in the interests of navigation on Delaware River, with particular emphasis on the reaches above Trenton, New Jersey. The studies included an analysis of existing navigation projects and their relationship to present and prospective maritime commerce, and an investigation to determine the desirability of modifying existing projects or providing additional improvements. Information was obtained from commercial statistics, prior reports, and contact with local interests.

SECTION II - HISTORY OF NAVIGATION

2-01. ABOVE TRENTON - Prior to the construction of railroads and canals, Delaware River above Trenton, although difficult to navigate, was an important highway of commerce. Early navigation was confined to small craft, or to log rafts which were brought down during spring and fall freshets, some from as far upstream as Hancock, New York. The boats first used were flat-bottomed scows which were floated downstream with the current and poled upstream. In about 1750, round-bottomed boats were introduced, and used extensively up and down the Delaware, navigating as far upstream as the Lackawaxen. These boats, known as "Durham" boats because they were first built at Durham Village, ten miles below Easton, carried about 20 tons of freight, and drew about five feet of water. In about 1810, flat-bottomed "arks" were introduced to bring coal down the river. These were merely rectangular pine boxes with drafts of only about two feet. Upon arriving in Philadelphia, the arks were dismantled, the lumber sold, and the iron-work sent overland to the headwaters, to be used in constructing new arks. Commerce by river boats and arks decreased rapidly when the Delaware Division of the Pennsylvania Canal opened in 1832, and practically disappeared with the completion of the Belvidere Delaware Railroad in 1857. Log rafts, however, continued in popular use for many years.

2-02. With the development of the coal industry in the upper Delaware River Basin, an extensive system of canals was constructed between 1825 and 1860 to transport coal between points in the Delaware watershed, and between the Delaware and Hudson River watersheds. Commerce on these canals reached its peak about 1860, and declined steadily until about 1900, when canal navigation activities practically ceased as rail competition increased.

2-03. BELOW TRENTON. From Trenton to the sea the Delaware is a tidal estuary, and is one of the principal navigable waterways of the United States. Henry Hudson visited the lower reaches of the Delaware in 1609 while searching for a route to the Indies. In the following year, 1610, Lord de la Warr, who had been dispatched from England to govern the English Colony at Jamestown, Virginia, is said to have entered Delaware Bay, and it is his name that the river bears today. The early history of the Delaware is a mixture of Dutch, Swedish, and English influences. These three groups of early colonists feuded to control the river. In 1655 the Dutch drove the Swedes from the Delaware, and in 1664 the Dutch were in turn supplanted by the English. Extensive grants of land were soon made by the English, and large scale colonizing schemes were started. The river assumed a new importance following the establishment of William Penn's colony at Philadelphia in 1682. Philadelphia rapidly became the grain and lumber mart of the Atlantic Coast. In 1735 the number of vessels which arrived and cleared the Port was 427.

2-04. In 1834 the Delaware and Raritan Canal, which was constructed by a private company, was placed in operation. The canal provided a connection between Raritan River at New Brunswick, N. J. and Delaware River at Bordentown, N. J., via Bound Brook, Princeton, and Trenton, a distance of 44 statute miles. It had 14 locks and was nine feet deep with a bottom width of 50 feet. A feeder canal 23 miles long, with an intake in Delaware River near Raven Rock, N. J., provided the canal with the necessary water supply. The greatest draft permitted in the canal was seven feet, and the greatest vertical clearance was 50 feet. A maximum speed of 4½ miles per hour was allowed, and the theoretical time of transit from Bordentown to New Brunswick was 14 hours. The canal was leased to the Pennsylvania Railroad in 1871, which operated it until 1932. It was closed to navigation in 1933, and its ownership transferred to the State of New Jersey. Since acquisition, the canal has been rehabilitated by the State for the delivery and sale, to industries and public supply systems, of water diverted from Delaware River in accordance with rights approved by the United States Supreme Court.

2-05. Delaware River below Philadelphia in its natural condition had a channel 175 feet to 600 feet wide and a controlling depth of 17 feet determined by numerous shoals and sand bars. In its original condition the section of river above Philadelphia, to the head of natural navigation at Trenton, was obstructed by shoals and navigable by a narrow and circuitous channel having a depth of three to six feet at mean low water over some of the shoals. Delaware River has been improved for navigation by the United States from its mouth to the head of tide at Trenton. The earliest improvements in the interest of navigation were the construction of ice harbors and breakwaters to provide safe havens from ice and storms. The earliest and most notable of these structures

was a massive stone breakwater located at Cape Henlopen, Delaware. Work on this structure was begun in 1828. During these early times the vessel traffic on Delaware River consisted of sailing ships plying between foreign ports, and river and canal barges using the many tributary streams and canals that terminate in Delaware River. Some of these tributaries, for example the Schuylkill and Christina Rivers, still are of major importance to the economic and industrial development of Delaware River, and their downstream reaches have been developed and improved for navigation.

2-06. The advent of ocean-going steamships made prearranged scheduled sailing a reality, and started the race for larger deeper-draft vessels. This, along with the continual increase of water-borne commerce, resulted in the need for improved navigation conditions. The first comprehensive project for the improvement of Delaware River for navigation was started in 1885. Subsequent to completion of this project, further improvements in Delaware River were authorized, culminating in the present 40-foot project. The modifications to the original project have been made to provide navigation facilities and a safer, more adequate channel extending farther upstream, to accommodate the increasing number and size of ships carrying the growing volume of commerce transported over the Delaware River.

SECTION III - PRIOR REPORTS

3-01. Pertinent prior reports are reviewed in the following subparagraphs:

a. There have been a number of prior reports on proposed projects in the interest of navigation on Delaware River above Trenton. The first Federal examination on the subject was authorized by the River and Harbor Act of 1872. A plan was presented for improving the river between Easton and Trenton for raft navigation by removing boulders and ledge rock, dredging bars, and constructing wing dams. There is no record of any appropriation having been made to carry out this work.

b. A preliminary examination report on the Delaware between Trenton and Port Jervis, N. Y. was printed in the annual report of the Chief of Engineers for 1884. The report was unfavorable, concluding that only the rapidly declining lumber industry would benefit by improvements, and that the section of river below Easton was already adequately provided with transportation facilities such as canals and railroads.

c. A preliminary examination of Delaware River between Trenton and Easton was authorized by the River and Harbor Act of 22 September 1922. The District Engineer pointed out that considerable tonnage might be attracted to an improved waterway extending to Easton, that would not otherwise use the waterway, if the improvement were extended above Easton up the Delaware and Lehigh Rivers for short distances. It was concluded (1) that the success of such a project would be doubtful without the additional tonnage which might use it as a feeder to the proposed New Jersey Ship Canal connecting Delaware River and New York Harbor; (2) that under no conditions should the upper Delaware improvement be provided prior to construction of the New Jersey Ship Canal; and (3) that development of water power in connection with any navigation improvement was of little importance. The report, with an unfavorable recommendation by the Chief of Engineers, was sent to Congress in 1924, but was not printed.

d. House Document 245, 72nd Congress, 1st Session, is a preliminary examination report ("308" report) on Lehigh River, Pa. In the navigation phase of this report discussion was made of a plan for canalizing Delaware River from Trenton to Easton and beyond, with a branch extending up the Lehigh to the vicinity of Siegfried. The Chief of Engineers concluded that improvement of Lehigh River for navigation would not serve a useful purpose except in conjunction with the improvement of Delaware River above Trenton, to be considered in a later report to be submitted on Delaware River.

e. House Document 179, 73rd Congress, 2nd Session, is a preliminary examination report (the Delaware River "308" report) on the Delaware River watershed above Trenton, N. J. Although the report considered all phases of water resources development, only the navigation phase of this report is reviewed here. The report presented a plan for extending barge navigation above Trenton, by means of a proposed waterway designed to accommodate tugs and barges with a loaded draft of 10 feet. It would extend from Trenton to Martins Creek, Pa. about seven miles above the mouth of Lehigh River, with a branch extending up the Lehigh to Siegfried, 24 miles above its mouth. The plan provided for 14 locks and dams on Delaware River and nine on the Lehigh. The proposed waterway was found to be economically infeasible. In his review of the entire report, the Chief of Engineers concluded that no additional improvements for navigation, power development, flood control, irrigation, water supply, or any combination thereof, should be undertaken at that time.

f. Cross Jersey Ship Canal

House Document 219, 73rd Congress, 2d Session described a plan for the New York Bay-Delaware River Section of the Intracoastal

Waterway. The plan called for a canal generally paralleling the route of the Delaware and Raritan Canal, with a project depth of 27 feet and bottom width of 250 feet. The single pool would have an elevation of 10 feet above mean low water and would be formed by the construction of two dams with movable crests, one in the Delaware near Bordentown and the other in Raritan River near Sayreville. House Committee Document 93, 74th Congress, 2d Session, is a report on a study made to determine the advisability of constructing the waterway. A special board reported on the proposal, and recommended the plan be changed to provide for a small dam in Crosswicks Creek and a pumping plant instead of the expensive dam in Delaware River. Senate Document 139, 79th Congress, 2d Session is a report on a study made to determine the advisability of constructing a waterway of lesser dimensions than discussed in House Committee Document 93. The Chief of Engineers recommended a ship canal generally in accordance with plans set forth in House Committee Document 93. No project for a cross Jersey waterway has been adopted.

SECTION IV - EXISTING PROJECTS

4-01. The existing navigation projects having authorized depths over 25 feet are listed in table E-1 which shows the name of each project, the date of the latest authorization, the authorized dimensions, the project length, project cost to 30 June 1959, current status, and commerce carried during calendar year 1958. The existing projects having authorized depths less than 25 feet are listed in table E-2 which shows the name of each project, the date of adoption or the latest modification, the authorized dimensions, the project length, current status, date completed, and commerce carried in 1958. Inactive projects are not listed. Plate 1 shows the locations of the streams listed in tables E-1 and E-2.

SECTION V - ADDITIONAL STUDIES AUTHORIZED

5-01. There are several additional studies authorized with a view to modifying existing projects or adopting new projects on both the main stem and on tributary streams. The presently funded studies which are pertinent to the considerations of this appendix are described in the following subparagraphs.

a. A study of Wilmington Harbor (Christina River), Delaware was authorized by two resolutions of the Senate Public Works Committee adopted 18 March 1953 and 14 February 1955. Prior reports were reviewed

TABLE E-1

EXISTING NAVIGATION PROJECTS - AUTHORIZED DEPTHS OVER 25 FEET
IN
DELAWARE RIVER WATERSHED

Project	Date of Latest Authorization	Dimensions (Feet)		Project Length (miles)	Project Cost (Total to 30 June 1959)		Current Status (% Completed)	Commerce - 1958 (Short Tons)
		Depth	Width		New Work	Maintenance		
Delaware River, Pa., N.J., and Del., Philadelphia, Pa., to the Sea	3 July 1958	37-40	400-1,000	96.5	$31,468,080	$88,557,040	45	74,229,488
Delaware River, Between Philadelphia, Pa., and Trenton, N. J.	3 Sept. 1954	35-40 (1)	300-400 (1)	30.5	28,604,021	2,697,287	33	12,808,225
Schuylkill River, Pa.	24 July 1946	22-33	200-400	6.5	2,753,038	12,465,937	98	16,300,660
Inland Waterway From Delaware River to Chesapeake Bay, Del. and Md.	3 Sept. 1954	35	450	46.0	20,296,742	24,376,445	23	9,145,768
Wilmington Harbor, Christina River, Delaware	17 Oct. 1940	7-30	100-400	9.5	1,130,533	9,312,313	99	2,911,721
Delaware River at Camden, N. J.	2 Mar. 1945	18-37	1,200 (2)	4.0	462,906	235,158	40	1,492,791

(1) Project also includes maintenance of a channel 12 feet deep and 200 feet wide from the Trenton Marine Terminal to the Pennsylvania Railroad bridge at Trenton, dredged under a previous project.

(2) Average width (includes adjoining width in harbor area outside 40-foot channel in Delaware River, Philadelphia to the Sea.)

TABLE E-2

EXISTING NAVIGATION PROJECTS - AUTHORIZED DEPTHS UNDER 25 FEET
IN
DELAWARE RIVER WATERSHED

Project(1)	Date of Adoption or Modification	Dimensions (feet) Depth	Dimensions (feet) Width	Project Length (Miles)	Current Status (% Completed)	Commerce - 1958 (Short Tons)	Remarks
Big Timber Creek, N. J.	30 Aug. 1935	10	60-75	5.5	100	103,472	Project completed in 1941
Cohansey River, N. J.	26 Aug. 1937	8-12	75-100	19.5	100	98,698	Project completed in 1939
Cooper River, N. J.	3 June 1896	12	70	1.75	100	82,100	Project completed in 1920
Harbor of Refuge, Del.	30 Aug. 1935	15	300	0.9(2)	100	174,962	Project completed in 1951
Inland Waterway - Rehoboth Bay to Delaware Bay, Del.	2 Mar. 1945	6-10	50-200	12.0	70	12,785	
Little River, Del.	25 July 1912	5	40-60	3.0	100	37	Project completed in 1914
Mantua Creek, N. J.	20 June 1938	7-20	60-110	7.0	100	296,132	Project completed in 1940
Maurice River, N. J.	30 Aug. 1935	7-8	60-150	24.0	45	15,833	
Mispillion River, Del.	3 Sept.1954	9	50-80	13.6	31	20,352	
Murderkill River. Del.	13 July 1892	7	80-150	8.5	63	1,657	
Raccoon Creek, N.J.	2 Mar. 1919	7	40-75	9.75	100	3,780	Project completed in 1922
St. Jones River, Del.	26 Aug. 1937	7	40-60	11.0(2)	40	120	
Salem River, N. J.	3 March 1925	12	100-150	5.0	60	41,389	
Smyrna River, Del.	25 June 1910	7	60-100	9.5	95	0	

(1) Excludes inactive projects
(2) Approximate

to determine the advisability of increasing the depth and width of the channel in Christina River from its mouth to the Lobdell Canal, a distance of about 0.8 mile. Views of local interests are discussed in paragraph 7-01c. Reports favorable to deepening the waterway to 35 feet have been made by the District and Division Engineers and the Board of Engineers for River and Harbors. Formal comments of Federal and State interests are being obtained prior to transmission of the report of the Chief of Engineers to Congress.

b. A survey study of channel dimensions and anchorages in Delaware River between Philadelphia and the sea was authorized by resolutions of the Committees on Public Works, of the United States Senate and House of Representatives, adopted 1 and 16 March 1954, respectively. An interim report covering modification of anchorage areas was submitted to Congress, printed as House Document 185, 85th Congress, 1st Session, and the modifications recommended therein were authorized by Congress in the River and Harbor Act approved 3 July 1958. Survey investigations are under way to determine whether any modifications of channel dimensions and anchorages are advisable. Views of local interests are presented in paragraph 7-01 b.

c. A survey study of Delaware River to consider a branch channel in the vicinity of Delaware City, Delaware, was authorized by resolutions adopted 13 July 1954 and 28 May 1958, respectively, by the Committees on Public Works of the House of Representatives and the United States Senate. Investigations are under way to determine the feasibility of construction and maintenance of an additional branch channel connecting with the present main channel at points both north and south of Pea Patch Island, near Delaware City, Delaware. Views of local interests on the proposal are presented in paragraph 7-01e.

SECTION VI - TERMINAL AND TRANSFER FACILITIES

6-01. PIERS, WHARVES AND DOCKS. There are 396 piers, wharves and docks on Delaware River and its tributaries between Trenton, N. J. and the sea. These are listed in the Corps of Engineers Port Series No. 7, revised 1955, "The Port of Philadelphia, Pa. and Camden and Gloucester City, N. J." and Port Series No. 8, revised 1955, "The Port of Wilmington, Delaware and Ports on Delaware River below and above Philadelphia, Pa." Fifteen of the above piers are owned by the United States, four by the States of Pennsylvania, New Jersey and Delaware, 49 by municipalities, 55 by railroad companies, and 273 by other private interests. The piers are located as follows: 169 on the waterfront of Philadelphia; 77 in the corresponding reach of Delaware River on the New Jersey waterfront which includes Camden, Gloucester City, and several small communities; 35 are above Philadelphia, and 115 below Philadelphia. The public and

railroad piers are open to public use, some free and others on payment of charges. Most of the piers which are equipped to handle general cargo have direct rail connections with the three railroad systems in this area.

6-02. WAREHOUSE AND STORAGE SPACE. The warehousing facilities include 27 dry cargo warehouses having approximately 13.6 million square feet of covered storage area located directly on the piers or within 1,500 feet of general cargo piers. In addition, over 9 million square feet of open storage space is available adjacent to the waterfront. There are seven cold storage warehouses with 11.9 million cubic feet of refrigerated storage space. The port area has oil storage tanks with a capacity of more than 35,000,000 barrels and additional facilities are under construction. The three Trunk Line rail carriers maintain classification and storage yards with a combined capacity for approximately 35,000 cars, in addition to their port terminal facilities.

6-03. HANDLING FACILITIES. The Philadelphia port area has ore handling equipment on three railroad piers having a combined unloading capacity of 6,600 tons per hour. In addition, the United States Steel Corporation operates a new facility at its Morrisville plant that is capable of unloading two ships simultaneously at a combined rate of 2,200 tons per hour. The port of Philadelphia has two grain elevators with a total capacity of 4.7 million bushels. Vessels are loaded with grain at the rate of 150,000 bushels an hour. Three coal piers are equipped with mechanical dumpers having a combined rated capacity of 3,450 tons per hour. Two thaw houses with a combined capacity of 100 cars are available for handling frozen carloads of coal. Fixed and mobile cargo-handling equipment include stiffleg derricks having lift capacities of from 5 to 100 tons; floating derricks with lift capacities up to 108 tons; 7 to 30-ton gasoline crawler cranes; 25 to 60-ton diesel crawler cranes, 12 to 35-ton steam locomotive cranes; 45 and 50-ton diesel electric locomotive cranes; 5 to 75-ton electric traveling and revolving gantry cranes; and bridge cranes up to 35-ton capacity. A 350-ton crane at the Philadelphia Naval Base is available to private interests if circumstances warrant it.

6-04. ADDITIONAL SERVICES. Various shipyards are located on Delaware River. These yards are capable of constructing or handling any size or type of ship for major overhaul and repair. Bunker and chandler services, customs brokers, freight forwarding and export packing services are all located close to the waterfront.

6-05. ADEQUACY OF FACILITIES. The existing terminal facilities permit full utilization of this water route for the existing commerce. Facilities are constantly being modernized and expanded to take care of the demands of prospective commerce.

SECTION VII - IMPROVEMENT DESIRED

7-01. VIEWS OF LOCAL INTERESTS

a. To obtain the views of local interests on needs for improvement for flood control, water supply, hydroelectric power, navigation and allied purposes in the Delaware River basin, four public hearings were held by the District Engineer in January 1956 in connection with the Delaware River comprehensive review. The hearings were held at Port Jervis, N. Y. on the 6th; Stroudsburg, Pa. on the 13th; Trenton, N. J. on the 20th; and Philadelphia, Pa. on 27 January 1956. During these public hearings local interests did not comment on navigation needs.

b. A public hearing was held in Philadelphia, Pa. on 12 June 1956 to obtain the views of local interests concerning proposed modifications in the existing channel dimensions and anchorage areas in Delaware River. Local interests indicated that they would accept, as an interim arrangement, the plan for improved anchorages presented in House Document 185, 85th Congress, 1st Session, (see paragraph 5-01b), and recommended that the existing project between Philadelphia and the sea be modified to provide for a channel generally 50 feet deep and 1,000 to 1,200 feet wide. No opposition was expressed to the proposed modification.

c. Views of local interests concerning improvements desired in Wilmington Harbor were obtained at a public hearing held in Wilmington, Delaware on 17 October 1956. Local interests stated that the present channel is inadequate, and proposed that it be deepened to 35 feet and widened to 600 feet for an approximate distance of 4,400 feet from the mouth of Christina River to the Lobdell Canal. No objections were made at the hearing to the improvements proposed.

d. A public hearing was held in Wilmington on 20 October 1958 for the purpose of obtaining authoritative information and views concerning the feasibility of constructing a salt-water barrier in Delaware River in the vicinity of New Castle, Delaware. The primary purpose of the structure would be to provide a source of fresh water for the future needs of the State of Delaware. Navigation interests expressed opposition to the barrier because of the detrimental effects it would have on navigation in the Delaware. A full discussion of the proposed barrier is contained in Appendix S.

e. An additional branch channel in Delaware River in the vicinity of Delaware City, Delaware was the subject of a public hearing held at Wilmington on 14 January 1959. The proponents of the project desire a branch channel 40 feet deep and 400 feet wide, running from Delaware City to New Castle and between Pea Patch Island and the Delaware shore. They foresee substantial benefits from the proposed improvement,

based on the prediction that the channel would (1) open for development approximately 4,000 acres of ideal industrial land; (2) attract an estimated 20 large industries to the locality, with attendant increases in population, tax revenue, retail trade, number of automobiles in the locality, etc.; (3) increase the value of land abutting the river; and (4) make navigation of the river safer. Many local residents and groups opposed the improvement on the grounds that (1) the influx of industry that could be expected would result in the degeneration of the presently residential area; (2) residential property values would decrease; (3) the proposed channel would be harmful to fish and wildlife in the vicinity; (4) recreation areas at and just below New Castle would be destroyed; and (5) New Castle would lose its status as a significant historical spot.

f. In December 1958 the District Engineer sent out letters of inquiry concerning the need for navigation improvements upstream from Trenton, N. J. The inquiry was directed to the members of the Delaware Basin Survey Coordinating Committee representing the States of Pennsylvania and New Jersey, and the City of Philadelphia; and to the Delaware River Basin Advisory Committee. The Advisory Committee carried the inquiry further by contacting others. Comments were received from the State of New Jersey, the Commonwealth of Pennsylvania, the City of Philadelphia, and commercial interests. The opinions expressed in these replies indicate that no significant need or desire exists for navigation improvements north of Trenton. Most of the individuals and organizations contacted expressed little or no interest in the subject, and indicated that they were not aware of any others who might have particular interest in the matter. Bethlehem Steel Company had no comment regarding the need or lack of need for navigation improvements on Delaware River above Trenton, but suggested that if such a need were established, consideration be given to extending the improvements up Lehigh River. The Lehigh Coal and Navigation Company stated it knew of no present need for navigation on the Delaware and the Lehigh, but urged that careful consideration be given to future needs in view of the economic growth of the region.

7-02. VIEWS OF NAVY DEPARTMENT. The Department of the Navy was invited to comment on the need for additional improvements for navigation. The following views were expressed by the Commandant, Fourth Naval District, in a communication sent to the Chief of Naval Operations 18 March 1959 in reference to phases of the comprehensive survey of water resources of the Delaware River basin of general interest to the Navy: - (1) Navy seaplane operations would not be feasible on existing or proposed reservoirs in the Delaware River basin. In addition, current plans do not contemplate the assignment of seaplanes at Naval Air Activities in the Fourth Naval District, so that the use of reservoirs would not be required for that reason. (2) The costs of maintaining naval vessels berthed at the Naval Base have been comparable to those at any fresh water port.

Periodic tests have shown that the degree of salinity in Delaware River and tributaries above Wilmington has decreased to the maximum acceptable for the effective control of teredos and other marine growths which flourish in brackish water. It is not believed that additional fresh water in Delaware River would result in any appreciable saving to the Navy in the present cost of maintenance. (3) The proposed Cross Jersey Ship Canal might be considered by the Navy for the use of mine sweepers, patrol and other small craft requiring passage via the protected intracoastal waterways from Norfolk, Virginia, to Boston, Mass. (4) The deepening of the Delaware River channel from the authorized depth of 40 feet to 50 feet as desired by local interests is not essential for the current naval requirements. However, it is the policy of the Navy Department to encourage and further such projects whenever they will enhance naval logistic support capability; hence the need for such port developments is recognized in the light of the continuing trend in developing deep-draft commercial vessels. (5) A review will be made of all factors pertaining to naval operations with the proposed barrier in the Delaware estuary, and recommendations will be made, after receipt of the recommendations of the Corps of Engineers in its report on the subject. (See appendix S.)

SECTION VIII - COMMERCE

8-01. ABOVE TRENTON. As a result of studies made in 1932 in connection with the "308" report on the Delaware River basin (see paragraph 3-01e.) it was estimated that at that time there was a potential tonnage of 1,039,000 tons annually for improved waterways on Delaware and Lehigh Rivers, and 2,065,000 tons annually for the proposed improved waterways on Delaware and Lehigh Rivers, combined with the Cross Jersey Ship Canal. The principal products involved were coal, cement, sand and gravel, and iron and steel. The report concluded that, in view of the cost of the improvement, the potential tonnage, and the prospective savings, a navigation project was not, and probably would not become, justified.

8-02. Investigations made in 1958 for the Delaware River comprehensive review have indicated that there is at present no waterborne commerce above Trenton, and that there is little likelihood that any significant amount of waterborne commerce could be developed in the foreseeable future.

8-03. BELOW TRENTON. The foreign and domestic waterborne commerce of the Philadelphia port area includes the following principal commodities; (a) Inbound: crude petroleum, iron ore, raw sugar, lumber and wood pulp, industrial chemicals, and miscellaneous general cargo; and (b) Outbound: petroleum products, iron and steel, coal, wheat and other grains, machinery, and miscellaneous manufactured products. Eighty-three percent of the

total foreign and domestic commerce during calendar year 1958 was accounted for by two industries: 72 percent by the petroleum industry, and 11 percent by the iron and steel industry. The magnitude and growth of commerce on Delaware River and its tributaries are shown on table E-3, which lists the tonnages for nine calendar years between 1938 and 1958, for every fifth year from 1938 to 1953, and for each year from 1953 to 1958. Tonnages listed under the "main stream" column include those on Delaware River, Schuylkill River and Wilmington Harbor; tonnages listed under "minor tributaries" column include all the remaining tributaries. Data for the "main stream" column were obtained by subtracting commerce on "minor tributaries" from the total commerce on Delaware River. A steady increase in commerce is noted between 1938 and 1957 except during the war years, represented by the 1943 data. Commerce declined slightly during calendar year 1958. The table shows that commerce on Delaware River and tributaries has increased 183 percent during the 21-year period 1938 to 1958.

TABLE E-3

COMMERCE

DELAWARE RIVER AND TRIBUTARIES

TRENTON, N. J. TO THE SEA

(Short Tons)

Calendar Year	Main Stream (1)	Minor Tributaries (Approx.)	Total Commerce
1938	33,552,354	650,000	34,202,354
1943	23,253,943	570,000	23,823,943
1948	55,880,990	1,130,000	57,010,990
1953	72,222,038	1,210,000	73,432,038
1954	78,377,731	1,130,000	79,507,731
1955	85,878,624	980,000	86,858,624
1956	96,344,341	990,000	97,334,341
1957	102,686,891	890,000	103,576,891
1958	95,819,472	923,000	96,742,472

(1) Includes commerce on Delaware and Schuylkill Rivers, and Wilmington Harbor, Delaware

8-04. The principal port on Delaware River is Philadelphia, located about 100 miles above the Capes at the Delaware Bay entrance. Sizable ports are located on Delaware River at Camden, N.J. across the river from Philadelphia, and at Trenton, N. J. about 33 miles above Philadelphia, and on two tributaries: Schuylkill River, which empties into Delaware River at Philadelphia, and Christina River, which empties into Delaware River at Wilmington, Delaware, about 29 miles below Philadelphia. Many smaller ports are located on Delaware River and on tributaries which empty into Delaware River or Delaware Bay. Table E-4 lists the major ports where the principal activities in general port commerce are concentrated, and their location above the Capes at the Delaware Bay entrance.

TABLE E-4

MAJOR PORTS

DELAWARE RIVER AND TRIBUTARIES

Port	Distance above Capes (Miles)	Port	Distance above Capes (Miles)
Delaware City, Del.	61	Paulsboro, N. J.	90
Deepwater Point, N. J.	70	Philadelphia Naval Base	93
Wilmington, Del.	71	Gloucester, N. J.	96
Claymont, Del.	77	Philadelphia, Pa.	100
Marcus Hook, Pa.	80	Camden, N. J.	100
Chester, Pa.	83	Penn Manor, Pa.(U.S. Steel)	126
Billingsport, N. J.	88	Trenton, N. J.	133

SECTION IX - VESSEL TRAFFIC

9-01. ABOVE TRENTON. Commercial vessel traffic above Trenton has been of little consequence since about 1900, when canal navigation activities practically ceased. Local interests have indicated neither a desire nor a need for navigation improvements above Trenton, and it is considered that there is no significant potential traffic.

9-02. BELOW TRENTON. The size and type of vessels using the channels and ports below Trenton are listed in table E-5, which shows the recorded movements of vessels (in foreign and coastwise traffic) on Delaware River between Trenton and the sea for the year 1958. In that year 2,463 deep-draft vessels drawing 30 feet and over comprised 16 percent of the total trips in the foreign and coastwise traffic. Tankers make up 84 percent of these vessels with drafts of 30 feet and over, indicating the size and volume of the petroleum industry in port traffic.

SECTION X - FLOW REGULATION

10-01. THE MINIMUM FLOWS AND THE ADDITIONAL FLOWS EXPECTED. Records are available from stream gages at many locations along Delaware River and its tributaries. Flow data are presented in table E-6 from gages on Delaware River at Riegelsville, N. J., Lehigh River at Bethlehem, Schuylkill River at Philadelphia, and Delaware River at Trenton. The gages at Riegelsville, Bethlehem and Trenton have been in continuous service since the year they were established. The gage on Schuylkill River at Philadelphia was in service between 1898 and 1912, and then in continuous operation since 1931. The minimum mean monthly discharge data were obtained from U. S. Geological Survey tabulations. It is estimated that additional water could be released to augment the flow in Delaware, Lehigh and Schuylkill Rivers when the basic plan of improvement, as outlined in Appendix Q, is in operation. The figures in the last column in table E-6 represent the minimum regulated flows expected by the year 2010 in the Lehigh River and Delaware River above Trenton, and the Schuylkill River and Delaware River below Trenton.

TABLE E-5

TRIPS AND DRAFTS OF VESSELS - 1958

DELAWARE RIVER, TRENTON, N. J. TO THE SEA

(FOREIGN AND COASTWISE TRAFFIC)

Draft (feet)	UPBOUND						DOWNBOUND					
	Self propelled vessels			Non-self propelled vessels		TOTAL	Self propelled vessels			Non-self propelled vessels		TOTAL
	Passenger and dry cargo	Tanker	Towboat or tugboat	Dry cargo	Tanker		Passenger and dry cargo	Tanker	Towboat or tugboat	Dry cargo	Tanker	
46	-	1	-	-	-	1	-	-	-	-	-	-
42	-	1	-	-	-	1	-	-	-	-	-	-
41	-	5	-	-	-	5	-	-	-	-	-	-
40	-	9	-	-	-	9	-	-	-	-	-	-
39	-	5	-	-	-	5	1	-	-	-	-	1
38	4	14	-	-	-	18	-	-	-	-	-	-
37	8	23	-	-	-	31	-	-	-	-	-	-
36	16	57	-	-	-	73	1	-	-	-	-	1
35	37	206	-	-	-	243	1	1	-	-	-	2
34	14	250	-	-	-	264	1	7	-	-	-	8
33	22	200	-	-	-	222	1	4	-	-	-	5
32	31	315	-	-	-	346	1	31	-	-	-	32
31	40	520	-	-	-	560	13	229	-	-	-	242
30	112	144	-	-	-	256	83	55	-	-	-	138
29	151	36	-	-	-	187	55	38	-	-	-	93
28	145	26	-	-	-	171	71	47	-	-	-	118
27	213	21	-	10	-	244	59	36	-	-	-	95
26	171	21	-	-	-	192	97	72	-	-	-	169
25	227	18	-	26	-	271	158	109	-	-	-	267
24	220	17	-	-	-	237	165	195	-	-	-	360
23	210	29	-	2	-	241	220	259	-	-	-	479
22	227	30	-	1	-	258	284	263	-	-	-	547
21	329	28	-	1	-	358	362	200	-	-	-	562
20	383	59	-	-	-	442	528	341	-	-	-	869
19	410	174	-	-	-	584	482	226	-	-	-	708
18 and less	1,623	442	176	34	103	2,378	1,839	558	177	44	124	2,742
TOTAL	4,593	2,651	176	74	103	7,597	4,422	2,671	177	44	124	7,438
Vessels drawing 30 feet and over	284	1,750				2,034	102	327				429

TABLE E-6

MINIMUM FLOWS EXPERIENCED AND EXPECTED

DELAWARE RIVER WATERSHED

Station	Year established	Drainage area (sq. mi.)	Minimum mean monthly discharge Month	Year	(cfs)	Min.regulated flow expected (cfs)
Lehigh River Bethlehem, Pa.	1902	1,279	Sept.	1932	374	725
Delaware River Riegelsville, N.J.	1906	6,328	Sept.	1908	(1,250 (2,320*	4,610*
Delaware River Trenton, N. J.	1913	6,780	Sept.	1932	(1,440 (2,410*	4,700*
Schuylkill River Philadelphia, Pa.	1898-1912 and 1931	1,893	Nov.	1910	229	550

* After completion of Cannonsville Reservoir and with operation of the New York Board of Water Supply reservoirs in accordance with U. S. Supreme Court decree of 1954.

10-02. EFFECT OF FLOW REGULATION ON NAVIGATION. There will be a small amount of regulated flow provided by the comprehensive plan as shown in table E-6, and the effect of this flow regulation on navigation is expected to be negligible, as discussed below.

a. Above Trenton. The investigations have disclosed neither need nor demand for extending navigation above Trenton. The small amount of low flow enhancement would not alter this situation.

b. Cross-Jersey Ship Canal. Studies made in 1946 indicated that the water requirements of the proposed Cross Jersey Ship Canal would be 803 cfs, of which 66 cfs could be obtained from local surface water flow, and 27 cfs from ground water infiltration. The remaining 710 cfs would have to be obtained by diversion from other sources. The flows from

the reservoirs proposed in the basin plan could be used for navigation only at the sacrifice of water supply and stream quality improvement benefits. There is no current demand for the Cross Jersey Ship Canal, but consideration can be given to providing the remaining 710 cfs from feasible sites in the Delaware watershed when the need arises.

c. Below Trenton. Delaware River below Trenton is tidal. The volume of river discharge is small compared to the volume of tidal flow. Stream discharges at Trenton have little effect on stages in the tidal portion of the river except in the upper reaches during period of extremely high runoff. Additional fresh water released during periods of low upland discharge would tend to raise the normal water elevation in the river above Trenton during those periods. However, this increase in discharge would provide no benefit to navigation as its effect on river stages would be of little consequence for purposes of navigation below Trenton. In addition, it is believed that there would be little reduction in channel shoaling below Trenton because of the upstream release of fresh water from reservoirs proposed in the comprehensive plan. These reservoirs might retain some small amount of material which is presently being removed during the course of maintenance dredging. However, it is believed that there would be little change in the cost of maintenance dredging in the Delaware River channel between Trenton and Philadelphia because of flow regulation.

d. Schuylkill River. The amount of regulated flows to be provided by the comprehensive plan on Schuylkill River is very small. The effect of this flow on navigation in the tidal portion of this stream is negligible.

SECTION XI - DISCUSSION

11-01. Navigation with rafts, barges and other shallow-draft vessels once played an important role in the economy of the Delaware River basin above Trenton, but interest in this form of transportation declined rapidly with the advent of the railroad and the motor truck. Delaware River in this section is characterized by relatively steep gradients and swift currents, and consists of a series of shallow pools separated by rapids or rifts. Improvement to provide suitable navigation facilities would be difficult and costly. There is, at present, little indication of either need or desire for navigation improvements above Trenton, and there appears to be little prospect that this situation will change. It is considered that the contemplated plan for development of water resources in the Delaware basin will not create a significant demand for navigation above Trenton, but that the plan will not prejudice future navigation if a need or demand therefor develops.

11-02. Delaware River below Trenton is tidal and well-suited for navigation improvements. It has developed into one of the most important navigable waterways in the United States. The river and its tributaries, along with appurtenant navigation facilities, have generally kept pace with the needs of maritime interests. Indications are that navigation in this section of the river will become increasingly important to the economy of the region. Commerce on many of the tributary streams has been adversely affected by motor trucks which are able to provide faster service and door-to-door service. However, much of the recent economic growth in the lower Delaware valley is directly related to the provision and maintenance of adequate navigation facilities in Delaware River and its major tributary streams and harbors.

11-03. It is anticipated that vessel traffic in Delaware River will increase consistent with the industrial growth of the Delaware valley below Trenton. It is recognized that the increase in vessel traffic will result in increased pollution in the river and bay. Existing Federal laws are considered adequate for the control of this problem.

11-04. The advisability of constructing a New York Bay - Delaware River section of the Intracoastal Waterway was considered in prior reports. The proposed project, known as the Cross Jersey Ship Canal, would require a fresh water supply, with approximately 710 cfs coming from the Delaware River watershed or other sources. Consideration can be given to modification of existing plans and projects or developing other feasible sites for this purpose if and when further study of the canal project is undertaken.

11-05. Flow regulation which would be provided by the basic plan for developing the water resources of the watershed would result in insignificant benefits to navigation. Augmented low flows above Trenton would not improve the economic feasibility of navigation in that reach, and additional fresh water flow which might be provided below Trenton would have little effect on river stages for navigation and would not reduce channel shoaling or the cost of maintenance dredging.

11-06. Consideration has been given to the construction of a salt water barrier in Delaware River near New Castle, Delaware. Any complete closure of the river in this reach would have a profound effect on navigation. This, and other considerations in connection with the proposed barrier, are discussed in Appendix S.

SECTION XII - CONCLUSIONS

12.01. It is concluded that the improvement of Delaware River above Trenton for navigation is not justified at this time.

12.02. It is further concluded that below Trenton, in the tidal reaches of the river, the interests of navigation are being adequately served by the existing projects and the additional studies which are authorized to investigate changing requirements and conditions.

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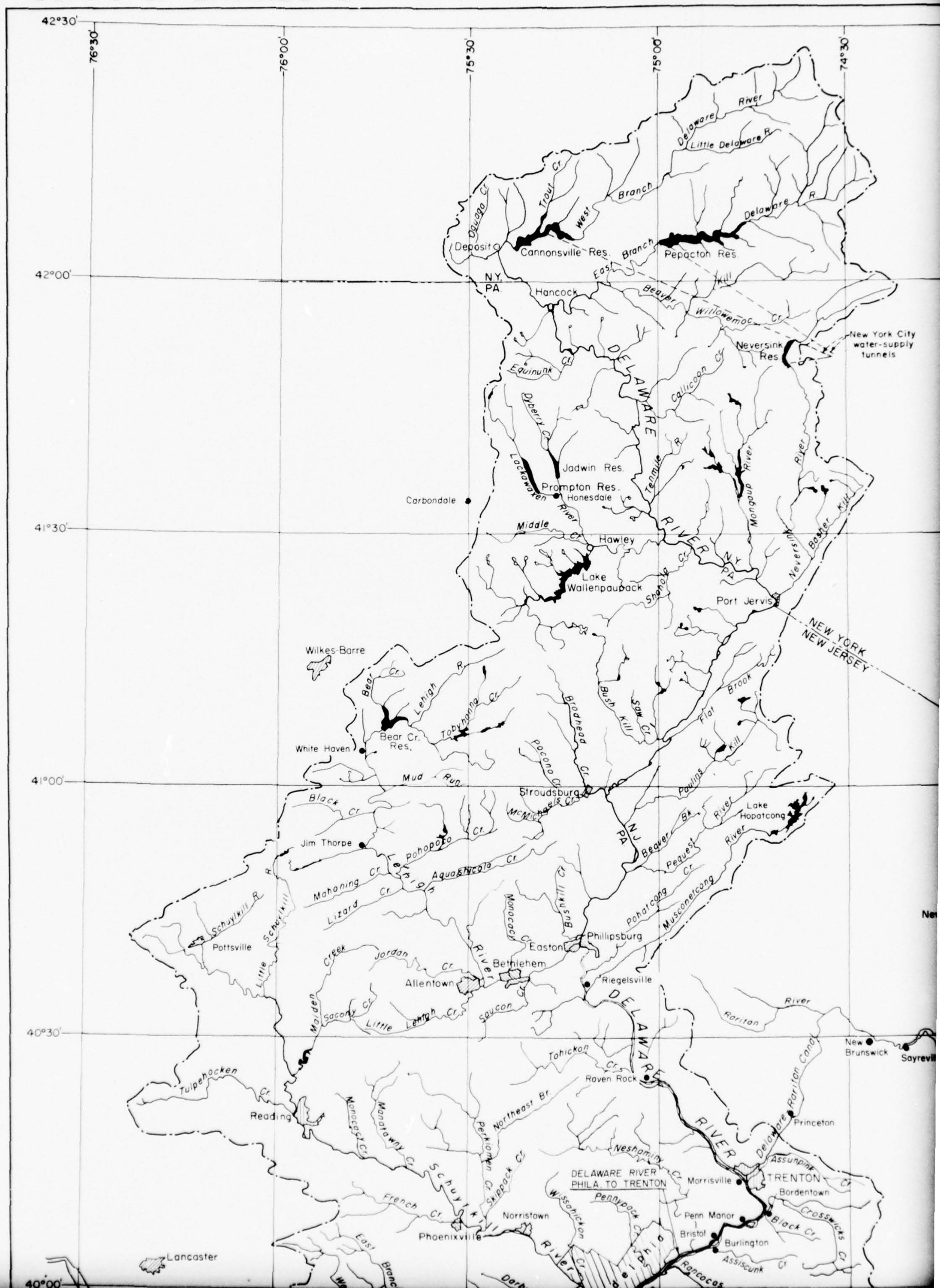
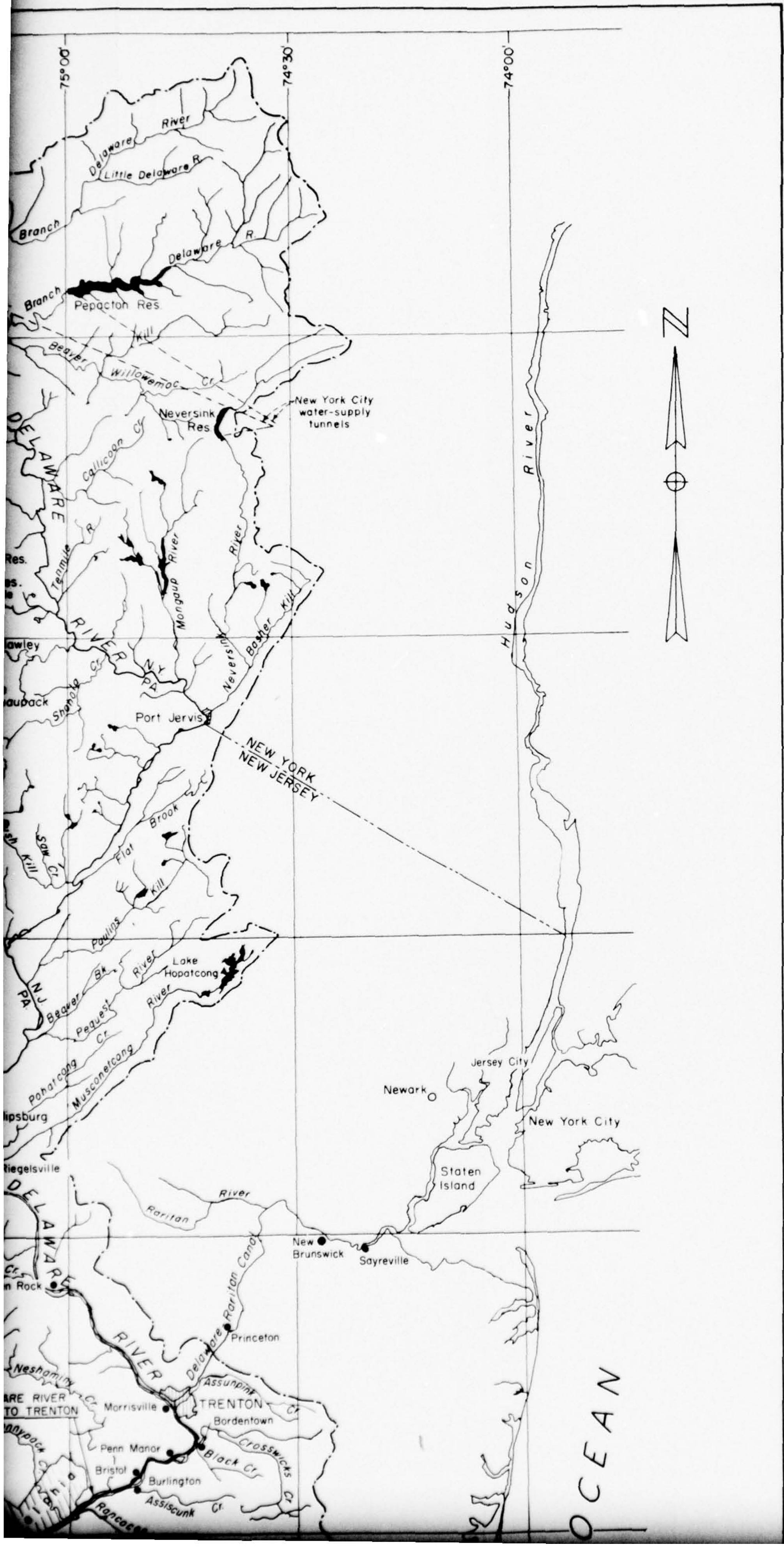
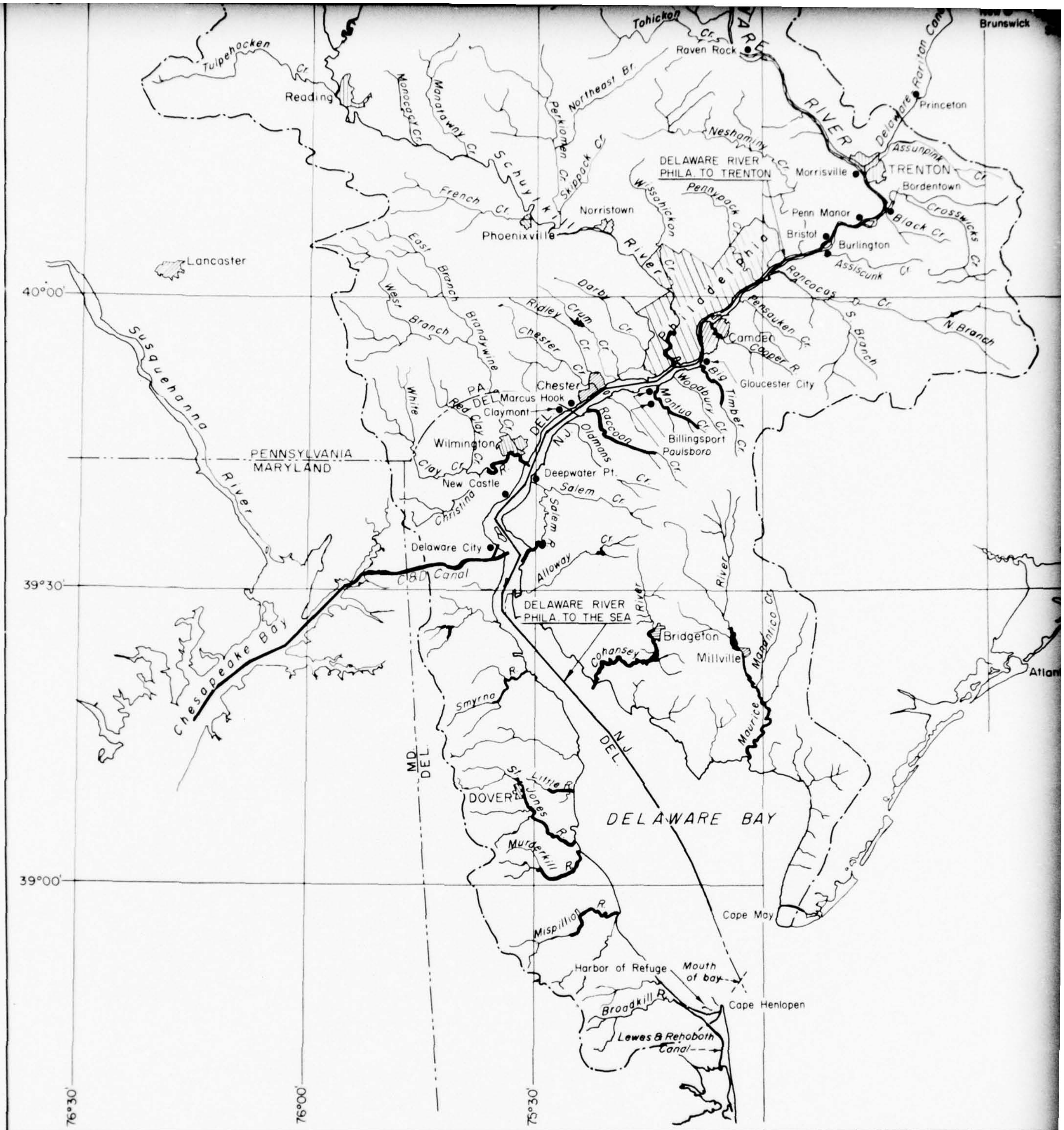


U. S. ARMY

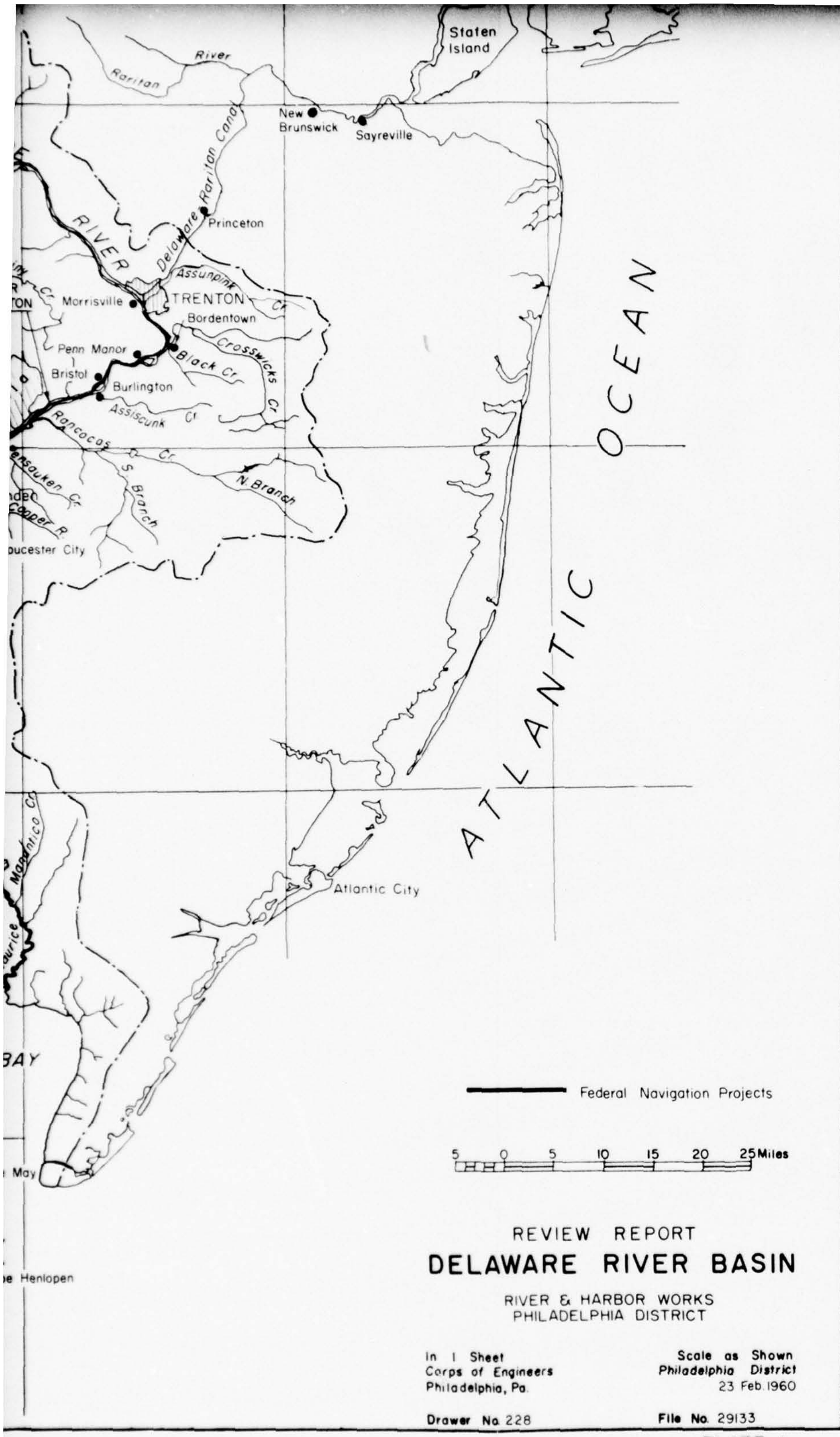


75°00'
74°30'
74°00'
Delaware River
Little Delaware R.
Branch
Delaware R.
Branch
Pepacton Res.
Kill
Beaver
Willowemoc Cr.
Neversink Res.
New York City water-supply tunnels
DELAWARE RIVER
Callicoon Cr.
Tenmile R.
Mongaup River
Neversink River
Basher Kill
Res.
Hawley
Shohola Cr.
NY
PA
Port Jervis
NEW YORK
NEW JERSEY
Hudson River
Flat Brook
Saw Cr.
Kill
Paulins Kill
Lake Hopatcong
NJ
PA
Beaver Bk.
Pequest River
Pequest Cr.
River
Pohatcong
Musconetcong
Jersey City
Newark
New York City
Riegelsville
Staten Island
DELAWARE
Raritan River
New Brunswick
Sayreville
Delaware Raritan Canal
Princeton
RIVER
Neshaminy Cr.
Assunpink Cr.
Morrisville
TRENTON
Bordentown
Penn Manor
Bristol
Burlington
Black Cr.
Crosswicks Cr.
Assiscunk Cr.
OCEAN
N

3



Tohickon Cr.
Raven Rock
New Brunswick
Tulpehocken Cr.
Reading
Monocacy Cr.
Manatawny Cr.
Schuylkill River
Perkiomen Cr.
Northeast Br.
Skippack Cr.
Neshaminy Cr.
Delaware Raritan Canal
Princeton
RIVER
Assunpink Cr.
DELAWARE RIVER PHILA. TO TRENTON
Morrisville
TRENTON
Bordentown
French Cr.
Norristown
Wissahickon Cr.
Pennypack Cr.
Penn Manor
Bristol
Burlington
Black Cr.
Crosswicks Cr.
Phoenixville
Lancaster
East Branch
West Branch
Brandywine
Philadelphia
Assiscunk Cr.
Rancocas Cr.
40°00'
Ridley
Crum
Darby Cr.
Chester Cr.
Pensauken Cr.
Camden
Cooper R.
S. Branch
N Branch
Susquehanna River
White Clay Cr.
Red Clay Cr.
PA
DEL
Marcus Hook
Chester
Claymont
Woodbury Cr.
Big Timber Cr.
Gloucester City
Mantua Cr.
DEL
NJ
Wilmington
Raccoon Cr.
Oldmans Cr.
Billingsport
Paulsboro
PENNSYLVANIA
MARYLAND
New Castle
Christina R.
Deepwater Pt.
Salem Cr.
Salem R.
Delaware City
Alloway Cr.
C&D Canal
39°30'
DELAWARE RIVER PHILA. TO THE SEA
Bridgeton
Cohansey River
Millville
Maurice River
Manumuskin Cr.
Chesapeake Bay
Smyrna R.
MD
DEL
NJ
DEL
DOVER
St. Jones R.
Little R.
DELAWARE BAY
Murderkill R.
39°00'
Mispillion R.
Cape May
Harbor of Refuge
Mouth of bay
Cape Henlopen
Broadkill R.
Lewes & Rehoboth Canal
76°30'
76°00'
75°30'


Staten Island
Raritan
River
New Brunswick
Sayreville
Delaware Raritan Canal
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Penn Manor
Bristol
Black Cr
Crosswicks Cr
Burlington
Assiscunk Cr
Rancocas Cr
S. Branch
N. Branch
Cooper R.
Maurice
ATLANTIC OCEAN
Atlantic City
BAY
Federal Navigation Projects
5 0 5 10 15 20 25 Miles
REVIEW REPORT
DELAWARE RIVER BASIN
RIVER & HARBOR WORKS
PHILADELPHIA DISTRICT
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.
Scale as Shown
Philadelphia District
23 Feb. 1960
Drawer No. 228
File No. 29133

PLATE I

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN

APPENDIX F

POWER MARKETS AND VALUATION OF POWER

PREPARED BY

FEDERAL POWER COMMISSION
NEW YORK REGIONAL OFFICE

FOR

U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
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PHILADELPHIA, PA.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLES

<u>PLATES</u>

DELAWARE RIVER BASIN SURVEY

APPENDIX F

POWER MARKETS AND VALUATION OF POWER

F-01 PURPOSE

The purpose of this study is to determine: (1) the past and estimated future electric power requirements of the Delaware River Basin Service Area; (2) the magnitude and characteristics of the markets which could absorb the output of potential hydro-electric projects on the Delaware River and its tributaries; and (3) power values or benefits associated with power installations at these projects.

F-02 SCOPE

The study of the power requirements of the Delaware River Basin Service Area includes a review of past requirements and develops estimates of future requirements to the year 2010. The estimates are based on a detailed analysis of growth of each of the principal classes of electric utility service and an extension of the indicated trends and rates of growth of total requirements to the year 2010.

The marketability and value of the hydroelectric power

potentialities of two multiple-purpose projects, Tocks Island and Hawk Mountain included in the basin plan, are treated in this Appendix. Other potential hydroelectric projects considered for development in the basin are discussed in "Appendix T - Hydro-electric Power."

F-03 FACTORS AFFECTING UTILITY POWER MARKETS

a. General The growth of power markets is affected by many economic and technological factors. Important among these are: the growth of population and number of households; expansion of industrial production and of activities associated with service, trade and professional establishments; widening application of known processes utilizing electrical energy; and the development of new uses of electrical energy in the home, industry and other fields of human enterprise. Under the impact of these influences the market supplied by the utilities has grown steadily over a long period of years in the past. Except for the effect of unforeseeable deterrents to its growth, this market may be expected to continue expanding for many years to come.

Considering the magnitude and characteristics of their power requirements, utility customers can be grouped into several classes of service. A brief review of each of the principal classes of utility service and of the factors affecting the growth of their

power requirements is presented in the following paragraphs.

b. Farm Service This class of service includes the requirements of utility customers residing in rural areas and depending upon agriculture for the major portion of their income. Farm customers utilize electric energy in their homes as well as in some of their farming operations. Electrification of the farm homestead brought to the farming population many comforts and conveniences, including labor savings, entertainment, improved sanitary conditions and many other advantages. The efficiency and economy of modern dairying, poultry raising and egg production depend upon the extensive use of electric energy. Other types of agriculture are also beginning to expand the use of this form of energy and considerable progress in this direction can be expected. Under favorable economic conditions in the future, use of electric energy will continue to expand in many farming operations and in processing agricultural products on the farm.

c. Non-Farm Residential Service This class of service includes, by far, the largest number of customers, most of whom live in urban and suburban areas. They use electric energy for lighting, heating, cooking, refrigeration, and the operation of numerous other household devices and appliances. The number of customers in this class of service is in direct relation to the

number of families or households. Annual energy consumption per customer is increasing steadily as the use of known appliances expands and new appliances are developed and marketed. Many domestic appliances have been in use for a long time and have already reached high degrees of saturation. Others have come into use only recently and will take some time to find wide acceptance. Still others are in the development stage and will stimulate annual use per customer in the years to come. Generally, this class of service is least affected by adverse economic conditions. Combined, the farm and non-farm domestic service group is sometimes identified as the Rural and Residential Class.

d. Commercial Service Commercial energy sales include deliveries to wholesale and retail trade enterprises, professional and personal service establishments, places of recreation, financial institutions and other business concerns. As population increases, there is greater need for the services provided by these establishments. Generally, commercial consumers utilize electric energy for lighting, air-conditioning and the operation of a great variety of appliances and equipment. Better lighting has proved very effective in stimulating business and improving the efficiency of trade establishments. Air-conditioning is fast becoming essential in department stores, theaters, restaurants and other competitive

enterprises. Electrification of office, store and shop equipment results in higher efficiency, labor savings and lower operating costs. Under these influences, the commercial service can be expected to continue its growth for many years to come.

e. Industrial Service The industrial class of service includes all energy sold to manufacturing and mining establishments. Electrical energy has been very effective in expanding industrial production, lowering costs, increasing efficiency and raising the productivity of labor. For the purposes of this study, estimates of the growth of energy use by industrial establishments are based on the assumption that favorable economic conditions would prevail over the period for which the estimates have been made and that short-period fluctuations in business conditions would not cause material changes in long-term trends. The estimates do not take into account any unforeseeable changes in power utilization by industries, nor the advent of any inventions or methods of production of goods which may radically change the known industrial uses of energy. Under these assumptions, industrial power requirements of the market under consideration will increase as existing industries expand their operations and new industries find it advantageous to locate in the area. Generally, the growth of industrial activity and of electric energy use by industries in the Delaware River Basin Service Area

can be expected to continue over an indefinite period in the future.

f. All Other Services The "All Other" classification includes sales to government establishments, military camps and depots, government warehouses, public schools, hospitals, libraries, municipal water supply systems, street and highway lighting, railways and railroads, and various miscellaneous customers not included in other classifications. The activities of government establishments can be expected to expand with population growth and the increased need for public services. Better lighting and electrification of service equipment in public buildings can also be expected. This is particularly true in the case of public schools and hospitals where the level of illumination is being steadily raised and where electrified equipment is more widely employed. Growth of population brings about greater demands for water and correspondingly increases the use of energy for pumping. With higher densities of population, street lighting levels are raised for traffic safety and crime prevention. Highway lighting can be expected to expand in the future as networks of roads become more extensive and complex. All of these factors will contribute to increased future energy sales onder the "All Other" class of service.

g. Total Requirements The expected growth of energy use by the various classes of service will result in greater transmission

and distribution losses. Added together, sales to ultimate consumers and the accompanying losses determine the total energy which utilities must provide by installing and operating adequate power supply facilities.

F-04 POWER REQUIREMENTS OF THE DELAWARE RIVER SERVICE AREA

a. Delineation of Area The Delaware River Service Area was delineated for the purpose of this Survey in consideration of the economic and other factors which must be taken into account in a plan for the comprehensive and most advantageous utilization of the water resources of the Delaware River and its tributaries. Estimates of the area's future electric power requirements are of great importance in the formulation of such a plan, particularly insofar as the utilization of the area's water resources of electric power generation and as condensing water for thermal plants are concerned.

As delineated, the area does not coincide with any of the Power Supply Areas designated by the Federal Power Commission for its studies of the Nation's electric power supply and requirements. The area selected for this power market study approximates the Delaware River Service Area and includes all of Power Supply Area 4 and approximately 70 percent of Power Supply Area 5. Plate F-1 shows this area as well as the principal utilities serving it.

b. Energy Requirements The estimates of the area's future power requirements were prepared in consideration of expected economic and technological developments in the demand for electric power. Past data were assembled and analyzed to determine significant trends and rates of growth. Estimates of future requirements were prepared for each class of utility service for the period 1960-1980 on the basis of data on future population, number of households, and expected industrial developments in the area as discussed in the Economic Base Study, Appendix B, prepared for this Survey by the Office of Business Economics of the United States Department of Commerce. Estimates of total utility requirements for the period 1985-2010 were made by extending the indicated trends of growth over the period 1940-1980, inclusive. Table F-1 and Plate F-2 show the past and estimated future utility requirements in the area for the entire period 1950-2010, inclusive.

It should be noted, that the estimates do not include allowances for uses of power which can not be properly evaluated at the present time, even though they may become quite appreciable in the distant future. On the other hand, it is realized that many known uses of energy will reach high levels of saturation long before the end of the estimating period. It is recognized, therefore, that estimates extending so far into the future as those presented in

this study should be reviewed at regular intervals, or as soon as an adequate evaluation of the impact of newly introduced uses of electric energy can be properly carried out.

c. Load Characteristics Future utility peak demands were determined by relating the estimated annual energy requirements to a series of future load factors. The annual load factors of utility systems are expected to improve gradually as a result of a expected greater use of electric energy by domestic and commercial customers and the expansion of automatic and remotely controlled operations in industrial production.

As estimated, the utility peak demands of the area will increase to a total of 34 million kilowatts in 1980 and to 96 million kilowatts in 2010. Compared with 1955, the estimates represent a growth of over 300 percent in 1980 and over 840 percent in 2010. The high levels of future peak demands are also a measure of the generating capacity which the utilities of the area will need to have in operation to supply the area's need for power.

F-05 MARKET FOR POWER FROM TOCKS ISLAND PROJECT

a. General The Tocks Island Project is located on the main stem of the Delaware River about 6½ miles above the Delaware Water Gap. The project site lies in the service area of the General Public Utilities Integrated System consisting of four subsidiaries

(two each in Pennsylvania and New Jersey) operating as a single system. In turn, GPU is a member of the well-known Pennsylvania-New Jersey-Maryland Interconnection. This large power pool is comprised of the following eight utilities: Public Service Electric and Gas Company, Philadelphia Electric Company, Pennsylvania Power & Light Company, Baltimore Gas and Electric Company, Pennsylvania Electric Company (GPU), Metropolitan Edison Company (GPU), New Jersey Power & Light Company (GPU), and Jersey Central Power & Light Company (GPU). In addition, several other private utility systems and industrial generating plants are included in the closely coordinated operations of the interconnection. Altogether, they supply nearly 99 percent of the utility power requirements in Power Supply Area 5, considered to be the market for the Tocks Island Project in this study.

The principal power generating stations and transmission lines of the utilities forming the interconnection are shown on Plate F-3.

b. Energy Requirements Electric utility service in this area, as in most other parts of the Nation, has grown from a rather modest beginning in the early part of the century. The first systems were small, with limited transmission and distribution facilities, and their service did not extend over very wide areas. With the growth of demand for electric power, particularly for domestic and

industrial use, and the progress made in the field of power generation and transmission, electric utility service began to expand rapidly. Interconnections between systems were followed by mergers and consolidations which eventually formed the present larger utility systems.

In 1940 the utilities in Power Supply Area 5 supplied their customers with a total of over 15.1 billion kilowatt-hours of energy. By 1957, their requirements increased to almost 48.3 billion kilowatt-hours, representing an over-all growth of over 218 percent in 17 years of operation. In the same period of time the combined noncoincident peak demand of the utilities increased from 3,026 to 9,147 megawatts. Table F-2, shows the growth of utility capacity and energy requirements in Power Supply Area 5 over the period 1940-1980, inclusive. Table F-3 shows the distribution of past and future utility energy requirements by class of service. The past and future utility total power requirements are also shown on Plate F-4.

The percent distribution of utility requirements by class of service over a long period of years reveals, generally, the characteristics of the market, prevailing long-term trends, and some indication of developments that are likely to take place in the future. The following table summarizes the percent distribution for the utility market in Power Supply Area 5.

Percent Distribution of Energy by Class of Service

	1940	1950	1957	1965	1970	1980
Rural and Residential	16.4	19.5	25.2	28.7	30.2	33.5
Commercial	14.8	15.0	16.4	15.9	16.2	16.2
Industrial	48.0	46.6	44.0	41.7	40.2	36.9
All Others	9.9	8.4	5.0	3.9	3.4	2.9
Losses	10.9	10.5	9.4	9.8	10.0	10.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

The estimates of utility energy requirements are based on certain assumptions and considerations regarding past trends and expected developments in the future. Minor deviations from expected trends should affect these estimates only to the extent of either advancing or retarding slightly the time when the indicated levels of energy requirements will be reached.

c. Load Characteristics The examination of the utility market in Power Supply Area 5 has concerned itself thus far with past and future energy requirements. No less important is the magnitude of the highest one-hour integrated demand which the utility power supply facilities are called upon to furnish. This maximum annual demand plus required reserves determine the dependable generating capacity which the utilities must have to insure adequate and reliable services.

The monthly pattern of system peak demands must be taken into account in planning an adequate power supply. In addition to supplying the actual peak load each month, consideration must be given to capacity out for maintenance, forced outages and errors in load forecasting. Setting up a suitable maintenance program is a complex procedure, especially for a large group of coordinated systems such as constitute the Pennsylvania-New Jersey-Maryland Interconnection. There has been a distinct change in the variation of monthly peak loads expressed as a percent of annual peak. Whereas in past years there was a pronounced valley during the summer months, which was of great help in scheduling needed maintenance. Utilities in general can no longer depend on this and must conduct their maintenance operations throughout the year. The increased use of air-conditioning and other changes in living habits affecting the consumption of electric energy have caused summer peaks to approach the winter ones in magnitude. In consequence, the importance of the actual time of occurrence of annual peak has been reduced to some extent, and the required capacity on a month-to-month basis for peak loads and total reserves for all purposes is subject to less variation than formerly. For the purpose of this study the estimated future annual peak demands are considered to occur in the evening during December.

The non-coincident peak demand of the utility load in Power Supply Area 5 increased from 3.03 million kilowatts in 1940 to 9.15 million in 1957, an increase of 202 percent as compared to an increase of 219 percent in energy requirements. As estimated for the future, the utility demand is expected to reach 14.34 million kilowatts by 1965 and 26.1 million by 1980. Table F-2 shows the past and future demand requirements in the market area over the period 1940-1980.

The ratio of average to maximum demand is the load factor and reflects to a degree the composition of the utility load. Over the period 1940-1957, the annual load factor for Power Supply Area 5 fluctuated considerably, varying as much as almost 10 percent from year to year, and reaching a peak of 64.9 percent in 1945. During the war years, intensive industrial activity with multi-shift production schedules and long work weeks brought about a considerable increase in the ratio of energy consumption to peak demand, resulting in load factors which may not be equalled for many years under peacetime conditions and normal 40-hour work-weeks. However, the expected growth of average annual consumption per customer in the rural and residential and commercial services, and the increasing use of energy in automatically and remotely controlled industrial operations should raise the overall utility annual load factors gradually.

It is estimated that the annual load factor of the utility load in Power Supply Area 5 will reach 63 percent by 1980.

d. Power Supply

1. Existing Generating Facilities There are 38 utility systems in Power Supply Area 5 which operate power generating facilities. Of these, 13 are part of the Pennsylvania-New Jersey-Maryland Interconnection and account for over 98 percent of all the power supply in the area. Table F-4 lists the installed capacity of all utility systems in the area, by type of prime mover, as of December 31, 1957.

The percent distribution of total utility capacity and generation by type of prime mover in 1957 is as follows:

	Capacity		Net Generation	
	Kilowatts	Percent	Million Kwh	Percent
Hydroelectric	710,355	7.0	2,670	5.6
Steam-electric	9,363,591	92.5	45,281	94.2
Internal Combustion	50,302	0.5	91	0.2
Total	10,124,248	100.0	48,042	100.0

In size, the utility plants in Power Supply Area 5 vary over a wide range. The largest hydroelectric plants are Conowingo (252,000 kilowatts) and Safe Harbor (230,555 kilowatts) both located on the Susquehanna River. The largest steam-electric

station is the Burlington plant of the Public Service Electric and Gas Company at Burlington, New Jersey, with an installed capacity of 490,000 kilowatts, and the Sewaren and Linden plants with 470,000 and 450,000 kilowatts, respectively. The Philadelphia Electric Company also operates two of the largest steam-electric plants in the area. They are, the Richmond plant with 450,000 kilowatts, and the Delaware plant with 436,250 kilowatts, both located in Philadelphia. The principal utility generating plants in Power Supply Area 5 are listed in Table F-5.

The name-plate rating of a generator is not always the true measure of its load carrying ability and many factors must be considered in determining this important characteristic. In general, large modern steam-electric units are conservatively rated and are capable of outputs in the order of 110 to 120 percent of their name-plate rating under normal operating conditions. On the other hand, older, smaller generators with low temperature/pressure levels must often be operated at less than their installed rating, thereby off-setting any gains in dependable capacity from newer units.

The dependability of hydroelectric capacity is a function of those factors that affect its utilization. Among the more important items which influence power output are: load factor and load curve shape of the absorbing system; hydraulic characteristics such as

head, flow, and available storage; external limitations imposed by other water uses such as navigation, water supply, and operational requirements of other plants on the same stream.

For the utilities of Power Supply Area 5, the installed and dependable capacities are shown in the following table:

Installed and Dependable Capacity of Power Supply Area 5
December 31, 1957
(Kilowatts)

	Installed	Dependable
Hydroelectric	710,355	686,680
Steam-Electric	9,363,591	9,745,950
Internal Combustion	50,302	49,065
Total	10,124,248	10,481,695

2. Retirement of Existing Capacity Data on retirement of utility generating units indicate that 40 years is a representative period of service for fuel-electric facilities and that no specific period is used for hydroelectric installations. While instances can be found of steam-electric units being retained for peaking or reserve capacity after 40 years of service, there are also numerous cases of capacity having been retired earlier. Estimates of expected retirements of fuel-electric capacity over the period 1965-1980 have been compiled

and are shown in Table F-6. As estimated, over three million kilowatts of fuel-electric capacity will be retired before 1980 to make way for more modern and efficient units.

3. Scheduled Capacity Additions Capacity additions definitely scheduled for installation in the immediate future are reported periodically to the Federal Power Commission by all electric utilities. The latest reports indicate that 2,737 megawatts of generating capacity will be installed by the end of 1960, and that an additional 1,947 megawatts will be installed by the end of 1963. This gives a total of 4,684 megawatts of capacity expected to be in operation and serving the area load by the end of 1963.

e. Future Capacity Requirements In determining the capacity which will have to be installed by the utilities in Power Supply Area 5 in addition to that definitely scheduled, consideration is given to the existing power supply, the estimated future load and reserve requirements, and expected retirement of obsolete and inefficient fuel-electric capacity. The reserve requirements for the utility systems in Power Supply Area 5 are estimated at 10 percent of the peak demand. This estimate was arrived at by a study of the reports of the Pennsylvania-New Jersey-Maryland Interconnection submitted to the Federal Power Commission for a number of prior years and by giving consideration to the degree of interconnection and coordination

among the systems in the area and the size of generating units in future installations.

Table F-6 shows the additional dependable capacity required to supply the future utility load in Power Supply Area 5. As estimated the utilities of the area must install an additional 1,963 megawatts of capacity to meet their requirements in 1965. During the next fifteen years, 1966-1980, further load growth and retirements of existing facilities will require the additional installation of over 16,500 megawatts of capacity.

In view of the magnitude of the future capacity requirements of Power Supply Area 5 it is evident that the output of the Tocks Island project, upon its completion, can be readily absorbed by the utilities serving the area.

F-06 UTILITY MARKET FOR POWER FROM HAWK MOUNTAIN PROJECT

a. Delineation of Area The market area considered most likely to absorb the output of the Hawk Mountain project is the service area of the Interconnected System of the New York State Electric and Gas Corporation. The area encompasses some 20 counties in the central portion of the State of New York, ranging as far south and east as Sullivan County and as far west as Wyoming County.

b. Energy Requirements Table F-7 shows the past power

requirements of this market during the period 1950-1958, and estimated future requirements for the years 1960-1980, inclusive. As shown in this table the energy requirements have grown from 1,921 million kilowatt-hours in 1950 to 3,178 million in 1958, an increase of over 65 percent in the eight-year period. During this same period of time the peak demand increased from 426 to 613 megawatts, an increase of almost 44 percent, while the load factor increased from 51.6 to 59.2 percent.

Table F-8 shows a breakdown of the total energy requirements by individual classes of service.

As estimated, the utility requirements in the Hawk Mountain market area will total 9.6 billion kilowatt-hours by 1980. The energy requirements by class of service from 1950 through 1980 are shown in Table F-8. The past and future utility total power requirements are also shown on Plate F-5.

The percent distribution of past and future total requirements by class of service is shown in the following table:

Percent Distribution of Energy by Class of Service

	1950	1955	1958	1965	1970	1980
Rural and Residential	32.4	33.8	35.3	37.3	38.5	40.4
Commercial	15.7	16.5	17.4	17.8	18.5	19.8
Industrial	31.3	29.2	26.6	24.3	22.5	19.7
All Other	5.8	6.7	6.8	6.9	6.8	6.6
Losses	14.8	13.8	13.9	13.7	13.7	13.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

c. Load Characteristics

1. Demand Requirements The peak demand of the utility load in this market increased from 426 megawatts in 1950 to 613 in 1958, a growth of 144 percent in the eight-year period. It is estimated that the peak demand will reach 900 megawatts by 1965 and 1,779 megawatts by 1980. Table F-7 shows the past and estimated future demands for the entire period 1950-1980, inclusive.

d. Power Supply

1. Existing Generating Facilities All generating capacity in the area is owned and operated by the New York State Electric and Gas Corporation. The Interconnected System of this utility operates six steam-electric and five hydroelectric power plants with a total installed capacity of 609,720 kilowatts.

Table F-9 lists each plant and its installed and dependable capacities as of December 31, 1957.

The hydroelectric plants of the area are relatively small, the largest being the Seneca Falls with 8,000 kilowatts. The largest steam-electric plants are the Greenidge Station at Dresden, New York, with an installed capacity of 160,000 kilowatts, the Goudey Station at Binghamton with 147,500 kilowatts and the Milliken plant at Ludlowville with 135,000 kilowatts.

2. Retirement of Existing Capacity On the basis of an average service life of 40 years and in consideration of past trends, it is estimated that 21,000 kilowatts of utility generating capacity in this area will be retired by 1965 and a total of 74,000 kilowatts by 1980.

3. Scheduled Capacity Additions Of the new capacity scheduled for installation, a new 135,000-kilowatt steam-electric unit was completed in the fall of 1958 at the Milliken Station in Ludlowville, and in addition a new unit of 135,000 kilowatts is scheduled for installation in 1960 at a plant in Somerset.

e. Required Additional Capacity for Carrying Future Loads The requirements for additional capacity were determined in the same manner as was done previously for Power Supply Area 5, except that the reserves for this market were taken at 12 percent of the annual peak demand.

Table F-10 shows the derivations of the additional capacity requirements. By 1960, the installation of 26 megawatts of capacity in addition to that already scheduled will be required. By 1980, the requirements for new capacity will increase to nearly 1,100 megawatts. In view of the indicated future capacity requirements in the area it appears that the output of the Hawk Mountain project, could be absorbed readily by its growing electric power requirements.

F-07 VALUATION OF POWER

a. General In most engineering studies, the economic feasibility of a proposed development is tested by cost comparisons with alternative methods of performing the same, or equivalent functions. The value of power at a proposed hydroelectric project is measured by the cost of providing an equivalent supply of power for the market under consideration from the most likely alternative source. The values are usually expressed in dollars per year per kilowatt of dependable capacity and mills per kilowatt-hour of average annual energy. They include the annual fixed and incremental costs of power production at the alternative source, the difference in annual transmission costs associated with the proposed project and its alternative, and all necessary adjustments for any inherent advantages of one source of power over the other.

b. At-Site and At-Market Power Values The value of power from potential hydroelectric developments may be determined either at the markets to be served, or at project sites. In determining economic feasibility, at-site values are usually compared with at-site costs.

At-market power values are based on the cost of power from the alternative source, plus the cost of transmission facilities to the principal load centers of the market area with appropriate adjustments. These values, reduced by the cost of transmitting the output of the proposed project to the same load centers, give the value of power at-site.

c. Alternative Sources of Power

1. General As developed previously in this appendix, the growing power requirements of utilities in Power Supply Area 5 and the Interconnected System of the New York State Electric and Gas Corporation in Power Supply Area 3 constitute the markets for power from the proposed Tocks Island and Hawk Mountain projects. The New York State Electric and Gas Corporation and most of the utilities in Power Supply Area 5 are privately owned. Existing generating capacity is predominantly steam-electric and current expansion programs call for the addition of considerable amounts of thermal capacity to meet their future needs. Reference is

made to Tables F-4 and F-9 showing the installed generating capacity as of December 31, 1957 by type of prime mover.

For this study therefore, privately owned, steam-electric plants of a size and characteristics likely to be used by utilities in the area are taken as the source of power alternative to the Tocks Island and Hawk Mountain projects.

2. Hydro-Steam Power Value Adjustments When applicable the power value adjustments referred to previously, consist of a capacity credit and energy credit, or debit, applied to the at-market cost of power from the alternative steam-electric source. There are certain advantages with respect to system reserve requirements, operating flexibility, service availability and other factors often associated with hydroelectric power when compared with fuel-electric power. The energy value adjustments are usually made when there is a substantial difference between plant factors of the proposed project and its alternative steam plant. In view of the amount of existing and planned future steam-electric capacity compared with hydroelectric capacity in the two areas, the widespread dispersal of generating stations, transmission systems linking power supply centers and load centers that permit the controlled movement of large amounts of power with reliability and flexibility, coupled with the high degree of integration and

coordination of operations, no adjustment of at-market cost of alternative power is considered warranted in this study.

3. Location and Capital Cost of Alternative Steam-Electric Plants Among the factors considered in selecting the sites of alternative steam-electric plants for Tocks Island and Hawk Mountain projects were the location of each site in relation to load centers and existing generating and transmission facilities in their respective market areas; current system planning of new facilities in each area; condensing water requirements; and fuel economies as governed by type, heat content, availability, and cost. Generating units employed were of a size compatible with system needs and practice of the particular utilities in whose service area the alternative steam-electric plants are assumed to be located.

There is wide variation in the construction costs of new steam-electric generating capacity throughout the country. Labor costs and freight charges on station equipment and construction materials depend on location. Other factors that effect the capital investment are: (1) site acquisition costs; (2) unusual construction difficulties, particularly with regard to foundations; (3) type of structure, whether outdoor, partially outdoor, or fully enclosed; (4) design characteristics such as temperature,

pressure, reheat, auxiliary equipment, etc.; (5) condensing water system; and (6) fuel handling facilities. Generally speaking, other conditions being equal, the unit cost (dollars per kilowatt) of new capacity decreases as the generating unit sizes increase. Optimum operating economy is usually achieved with the larger units.

The Tocks Island site on the Delaware River is about 10 miles upstream from Metropolitan Edison Company's new Portland steam-electric plant in Pennsylvania. The initial Portland unit of 150,000 kilowatts was placed in service in 1958. A second unit of 250,000 kilowatts is scheduled for completion in 1962. Therefore, for the purpose of evaluating the Tocks Island output an alternative steam-electric plant in the vicinity of Portland, consisting of three conventional coal-burning generating units of 250,000 kilowatts capacity each, is assumed. The capital cost of these units is estimated at $170 per kilowatt, based on July 1, 1958 price levels.

Power from the proposed Hawk Mountain project would be utilized on the Interconnected System of the New York State Electric & Gas Corporation. The project site is about 25 miles southeast from the company's Jennison steam plant at Bainbridge, New York. The size of largest units presently in operation or planned for the future on the system is 135,000 kilowatts. Therefore, for the Hawk Mountain project, an alternative steam-electric

plant near Bainbridge is assumed. The plant would have three conventional, coal-burning generating units of 150,000 kilowatts each. The estimated capital cost of these units, based on July 1, 1958 price levels, is $160 per kilowatt.

d. Annual Costs of Steam-Electric Power

1. General It is customary in the analysis of steam-electric power costs to divide the total annual expenses into fixed and variable components. Annual fixed or capacity costs consist of fixed charges on plant investment, interest on investment in reserve fuel supplies, and fixed fuel, operation, maintenance, administrative and general expenses. The remaining costs are the variable fuel and operation and maintenance expenses which are a function of the energy generated, and hence are known as incremental energy costs.

2. Fixed Charges Fixed charges on the investment in a steam-electric station consist of several components as discussed in the following:

Cost of Money Capitalization structures and return requirements of private utilities seldom remain static for extended periods. These factors also vary from system to system. There is, therefore, no precise method for arriving at an exact figure of the cost of money for a given area as a whole. However, reasonable estimates may be made on the basis of available records. Current

information indicates that a rate of 6.00 percent is representative and reasonable.

Depreciation The purpose of annual depreciation charges is to accumulate by the end of the service life of the facility under construction an amount equal to the original investment, less salvage value. In economic studies, it is convenient to employ sinking fund methods. The depreciation rate is then a function of the service life of the facility and the rate of interest on depreciation accumulations. Studies of steam-electric plant life expectancies indicate 35 years as a reasonable depreciation, or amortization period for modern stations operating an average of 4500 hours per year over their lifetime, although they may actually be retained in service beyond that time. To recover the original investment in such a station over its useful life, requires a yearly annuity with interest compounded at the going rate. Based on 6.0 percent interest and a 35-year service life, the annual depreciation is 0.90 percent of the capital investment.

Interim Replacements Since the sinking fund method of depreciation followed in economic studies does not cover those property elements having life spans of less than 35 years, annual provision must be made for their replacement. In the preparation of cost estimates, an allowance over the 35-year life of the plant

of 0.35 percent of the total investment is considered reasonable in recovering the investment in such short lived units of property.

Insurance The yearly cost of insurance for a typical steam-electric plant varies from 0.10 to 0.35 percent of the total investment. For the purpose of this study, 0.25 percent is considered representative.

Taxes Privately owned utilities, like any private enterprise, are subject to federal, state and local taxes. The tax component of annual fixed charges includes all taxes chargeable to electric operations. Taxes fall into three general classifications; federal income, federal miscellaneous, and state and local. From an accounting standpoint taxes are considered as operating revenue deductions, and only property (ad valorem) taxes are a direct function of plant investment. Income taxes are related to taxable income. It has long been the practice, however, in power studies to relate total taxes to plant investment. As with the cost of money, there is no simple method for computing tax deductions suitable or proper for general application. Therefore, provision for taxes is based on studies of actual taxes paid.

Following are the latest available average tax rates as percentages of investment in electric plant for the two utilities whose service areas were chosen as appropriate locations for the

alternative steam plants to be employed in this study.

Utility	Tax Rates in Percent of Investment	
	Federal Income (1955-57)	State and Local (1957)
Metropolitan Edison Company	3.69	1.04
New York State Electric & Gas Corporation	2.81	2.38

An average of 0.1 percent of the total investment is adopted to provide for those miscellaneous taxes levied by the Federal Government such as old age and unemployment and various excise taxes.

6. Summary of Fixed Charges Estimated average annual fixed charges in percent of capital investment as of July 1, 1958, for privately financed steam-electric plants alternative to the Tocks Island and Hawk Mountain projects are as follows:

Annual Fixed Charges
(Percent of Investment)

	Steam-electric Plant Alternative To	
	Tocks Island	Hawk Mountain
Cost of Money	6.00%	6.00%
Depreciation (35 year s.f.)	0.90	0.90
Interim Replacements	0.35	0.35
Insurance	0.25	0.25
Subtotal	7.50	7.50
Taxes		
Federal Income	3.69	2.81
Federal Miscellaneous	0.10	0.10
State and Local	1.04	2.38
Total Taxes	4.83	5.29
Total Fixed Charges	12.33	12.79

3. Interest on Investment in Reserve Fuel Stocks In order to assure the uninterrupted operation of fuel-electric generating stations, it is common procedure among operating utilities to maintain adequate reserves of fuel as a protection against the disruption of fuel deliveries through production or transportation contingencies. Analysis of available data indicates that current practice is to have on hand sufficient fuel for approximately 90 days of normal operation.

The annual cost of the investment in such fuel stocks is a part of the cost of producing power. The factors that enter into the determination of this charge are: (1) net plant heat rate; (2) average annual hours of operation; (3) cost of fuel; (4) number of operating days provided for by fuel reserves; and (5) the prevailing cost of money to the particular system maintaining the fuel reserves.

4. Operation and Maintenance Costs The fixed and variable components of total annual expenses incurred in the operation and maintenance of steam-electric generating stations, although a function of station size and amount of energy produced, are subject to wide variation and sometimes difficult to relate directly to plant characteristics. Among the influencing factors on such operation and maintenance expense are plant location, system policy, labor and materials costs, type of fuel burned, and the age and capacity factor of the plant.

The values recommended for this study are based on the continuing analysis of annual operating costs of a large number of steam-electric plants with a wide range of units installed over a long period of time. The figures are for the selected standard unit sizes in three-unit stations with an assumed service life of 35 years; average annual lifetime operation of 4500 hours; and distribution of fixed and variable components of cost in the proportion

of 65 and 35 percent, respectively.

The fixed and variable elements in the total annual operation and maintenance expense for the coal-burning units considered in this study are as follows:

Unit Capability (Kilowatts)	Operation and Maintenance Expenses Exclusive of Fuel: Fixed ($/Kw)	Variable (Mills/Kwh)
150,000	1.90	0.23
250,000	1.65	0.20

5. Fixed and Variable Fuel Costs The total fuel consumed annually by a steam-electric plant may be segregated into two components, fixed fuel and energy fuel. Fixed fuel is that part of the total fuel burned in a given period which is required to maintain the plant during no-load periods plus fuel equivalent to spinning reserve requirements. All other fuel consumption is the variable, or incremental component, and varies directly with station net generation.

Any allocation of fuel consumption into fixed and variable components takes into consideration the machine rating (including any seasonal limitations thereof), net plant heat rate and plant factor. Studies indicate that for estimating purposes the fixed fuel component represents 10 percent of total fuel consumed for coal-burning stations.

The type of fuel used by a utility in the production of electric energy depends in general on its availability and cost as compared to other kinds. Coal is burned exclusively on the systems considered for alternate steam plant locations in this study. The cost of coal on July 1, 1958 at Portland was approximately 36 cents per million Btu and at Bainbridge 34 cents.

6. Administrative and General Expenses There are certain fixed expenses of an administrative and general nature that are properly charged to various phases of utility operations. These costs include wages and expenses of officers and office employees, office supplies, legal expenses, welfare and pension funds, etc. Analysis of available information indicates that a representative allowance of this expense allocated to steam-electric power production is equal to 25 percent of fixed operation and maintenance expense, not including fuel.

7. Summary of Annual Costs of Alternative Steam-electric Power Summarizing the foregoing, the costs of power at the low-tension bus-bar of the alternative steam-electric plants are \$24.80 per kilowatt and 3.2 mills per kilowatt-hour for Portland; and \$24.50 per kilowatt and 3.1 mills per kilowatt-hour for Bainbridge. Included in the above capacity value are Federal, State and local taxes amounting to \$8.20/kilowatt-year for the former and

$8.45/kilowatt-year for the latter. Derivation of the cost of alternative steam-electric power is shown in detail in Table F-11.

e. Hydroelectric and Alternative Steam-Electric Transmission Requirements The value of the hydro power output at the high tension side of the project's step-up substation is generally equal to the cost of producing an equivalent supply at an alternative plant plus the annual costs of a step-up substation and transmission lines to market, less the annual cost of the transmission lines required to deliver the hydro project output to the same market.

At the alternative steam-electric plants the size of transformers required for handling capacity equivalent to the dependable capacities of the Tocks Island and Hawk Mountain projects would be 25,000 and 12,500 kilovolt-amperes, respectively. In both cases, these capacities would represent relatively small portions of considerably larger substation installations. The prorated capital costs of the required substation capacities are $146,000 and $66,900, respectively. The annual fixed charges, based on private financing, would be 12.33 percent for the Portland substation and 12.79 percent for Bainbridge. Operation and maintenance costs would be $0.22 per kilovolt-ampere. An allowance for the portion of total administrative and general expenses chargeable

to transmission facilities is taken at 20 percent of the annual operation and maintenance expenses. Estimated capital and annual costs of step-up substations at the alternative steam-electric plants are as follows:

	Portland (Tocks Island)	Bainbridge (Hawk Mountain)
Capital Costs	$146,000	$67,000
Annual Costs		
Fixed Charges	18,000	8,600
Operation & Maintenance	11,000	2,800
Administrative & General	2,200	600
Total Annual Costs	$31,200	$12,000

The Tocks Island project is only a few miles upstream from the assumed location of its alternative steam-electric plant. Therefore, the transmission distance for delivering the output from either source to an appropriate point on the Power Supply Area 5 network would be about the same. The firm and non-firm output of Tocks Island would require a double circuit, wood-pole, 115-kv line about 25 miles in length whereas for the alternative plant, a single circuit line of the same general characteristics is considered adequate.

The Hawk Mountain site is in the southeastern corner of the service area of the New York State Electric & Gas Corporation's interconnected system. This area is considered to be the logical market for the output from the Hawk Mountain plant. At the

present time there are no generating facilities in this area, power being supplied from the Jennison station at Bainbridge, New York, and from other more distant steam-electric plants by means of a 115-kilovolt transmission network. The Hawk Mountain hydro plant would require the construction of a new single circuit, wood pole, 115-kv line about 10 miles in length to deliver its output to an existing line which runs to the Hazel substation. For the alternative plant, the transmission line to the same network would be about 16 miles in length.

Annual costs of transmission lines are made up of the same components as for substations, namely; fixed charges, operation and maintenance, and administrative and general expenses. The fixed charges consist of interest, depreciation or amortization, interim replacements and insurance. Private financing at 6.0 percent interest rate was assumed for lines associated with the alternative power plants; federal financing at 2.5 percent for lines serving the Tocks Island project; and non-federal public financing at 4.5 percent for the Hawk Mountain transmission line. Capital and annual costs of transmission lines are as follows:

Projects	Capital Cost $	Interest Rate %	Annual Costs Fixed Charges $	O&M Adm. & Gen. $	Total $
Tocks Island	932,000	2.5	42,100	8,500	50,600
Alternative Steam	660,000	6.0	79,400	5,000	84,400
Hawk Mountain	231,000	4.5	13,900	3,500	17,400
Alternative Steam	370,000	6.0	46,200	5,200	51,400

f. At Site Power Values (High Tension Side of Hydro Substation)

Power values at the high tension side of the step-up substation of the hydro projects are obtained by adding to the annual costs of the alternative steam plants (Table F-11), the annual costs of steam-electric transmission facilities less the annual cost of the hydro transmission lines with allowance for losses. The latter were found to be relatively small and approximately equal for both hydro and steam and therefore were not included in the calculations. On the above basis the at-site power values applicable to the dependable capacity and average annual output of the proposed Tocks Island and Hawk Mountain projects together with "taxes foregone" are as follows:

At-Site Power Values (High Tension Side Step-up Substation)

	Tocks Island	Hawk Mountain
Capacity Value	$28.00/Kw/Yr.	$28.70/Kw/Yr.
Energy Value	3.2 mills/Kwh	3.1 mills/Kwh
Taxes Foregone	$10.15/Kw	$10.55/Kw

F-08 SUMMARY AND CONCLUSIONS

The formulation of a plan for the comprehensive and most

advantageous utilization of the water resources of the Delaware River and its tributaries must necessarily take into account the various economic, technological and other factors of the area which would be affected by such a plan. This appendix presents a study of several of these factors, including the demand for and supply of electric power in the affected area, the marketability of power from potential hydroelectric power sources in the basin and the values of such power in terms of the cost of an equivalent supply from appropriate alternative sources. The conclusions are as follows:

1. The area which would be affected by any plan for the Delaware River and its tributaries contains one of the largest concentrations of population and industry in the country. The electric power requirements of this area exceeded 55 billion kilowatt-hours in 1957 with a peak demand of 11.1 million kilowatts. Over the period of the next 50 years, these requirements will increase nearly nine times the present level and will require a nearly equivalent expansion of the area's power supply resources. Adequate supplies of water will be essential to the development and economic performance of the required additional generating capacity.

2. The output of the Tocks Island project could be readily utilized by the utilities of Power Supply Area 5, particularly by

the so-called Pennsylvania-New Jersey-Maryland Interconnection. This group of utilities will require the installation of over 16.5 million kilowatts of capacity by 1980 to take care of their expected load in that year.

3. The output of the Hawk Mountain project would find a ready market on the Interconnected System of the New York State Electric & Gas Corporation. To meet its future load this system will require the installation of nearly 1.1 million kilowatts of new generating capacity between 1960 and 1980.

4. The at-site power values or benefits of Tocks Island and Hawk Mountain projects were determined from the cost of producing equivalent supplies of power by steam-electric plants at Portland, Pennsylvania and Bainbridge, New York, plus the cost of steam transmission facilities less the cost of the required hydro transmission lines. Based on capital and annual costs as of July 1, 1958 the unit at-site power values at the high tension side of the hydro projects substations are $28.00 per kilowatt of dependable capacity and 3.2 mills per kilowatt-hour of average annual energy for the Tocks Island project and $28.70 per kilowatt and 3.1 mills per kilowatt-hour for the Hawk Mountain project. Included in these capacity values are "taxes foregone" amounting to $10.15 and $10.55 per kilowatt, respectively.

TABLE F-1

PAST AND ESTIMATED FUTURE UTILITY POWER REQUIREMENTS IN DELAWARE RIVER SERVICE AREA

1950-2010

Year	Energy for Load (Millions of Kwh)	Peak Demand (Thousands of Kw)	Load Factor (Percent)
1950	35,028	7,403	54.1
1955	49,027	10,145	55.2
1957	55,142	11,106	56.7
1960	66,600	13,440	56.4
1965	88,100	17,490	57.5
1970	113,900	22,230	58.5
1975	144,500	27,720	59.5
1980	180,400	34,000	60.4
1985	222,100	41,500	61.3
1990	270,300	49,600	62.2
1995	325,700	59,000	63.0
2000	389,000	69,500	63.7
2005	461,200	82,000	64.3
2010	543,500	96,000	64.8

TABLE F-2

PAST AND ESTIMATED FUTURE UTILITY POWER REQUIREMENTS IN POWER SUPPLY AREA 5
1940-1980

Year	Energy for Load (Millions of Kwh)	Peak Demand (Thousands of Kw)	Load Factor (Percent)
1940	15,144	3,026	55.2
1945	22,182	3,903	64.9
1950	30,466	6,020	57.8
1955	42,154	8,556	56.3
1957	48,265	9,147	60.2
1960	59,400	11,300	60.0
1965	76,500	14,340	60.9
1970	96,000	17,760	61.7
1975	118,800	21,720	62.4
1980	144,100	26,100	63.0

TABLE F-3

PAST AND ESTIMATED FUTURE DISTRIBUTION OF UTILITY ENERGY REQUIREMENTS IN POWER SUPPLY AREA 5 BY CLASS OF SERVICE
1940-1980
(Millions of Kwh)

Year	Rural and Residential	Commercial	Industrial	All Other	Total Deliveries	Losses	Energy for Load
1940	2,476	2,243	7,266	1,504	13,489	1,655	15,144
1945	3,372	2,947	12,163	1,670	20,152	2,030	22,182
1950	5,920	4,573	14,201	2,665	27,259	3,207	30,466
1955	10,198	6,791	18,572	2,396	37,957	4,197	42,154
1957	12,173	7,934	21,216	2,396	43,719	4,546	48,265
1960	15,850	9,340	25,900	2,610	53,700	5,700	59,400
1965	21,930	12,200	31,900	2,950	68,980	7,520	76,500
1970	29,030	15,500	38,600	3,290	86,420	9,580	96,000
1975	37,630	19,300	46,100	3,640	106,670	12,130	118,800
1980	48,300	23,400	53,200	4,100	129,000	15,100	144,100

TABLE F-4

INSTALLED CAPACITY OF UTILITY GENERATING PLANTS IN POWER SUPPLY AREA 5
December 31, 1957
(Kilowatts)

Company	Hydro	Steam	Internal Combustion	Total
Atlantic City Electric Company		275,500		275,500
Baltimore Gas & Electric Company		955,500		955,500
Delaware Power & Light Company		207,500		207,500
Eastern Shore Public Service Company		166,100	8,284	174,384
Jersey Central Power & Light Company		357,224		357,224
Lansdale Municipal System		12,000		12,000
Metropolitan Edison Company	19,620	481,500		501,120
New Jersey Power & Light Company		123,100		123,100
Pennsylvania Electric Company	52,700	853,867		906,567
Pennsylvania Power & Light Company	148,800	1,128,250		1,277,050
Philadelphia Electric Company	252,000	2,096,250		2,348,250
Public Service Electric & Gas Company		2,554,300		2,554,300
Safe Harbor Water Power Corporation	230,555			230,555
United Gas Improvement		75,000		75,000
Vineland Municipal System		33,500		33,500
Minor Systems	6,680	42,000	42,018	92,698
Total	710,355	9,363,591	50,302	10,124,248

TABLE F-5

PRINCIPAL UTILITY GENERATING PLANTS IN POWER SUPPLY AREA 5
December 31, 1957

Company	Plant Name	Capacity (Kilowatts)	Prime Mover	Location
Atlantic City Electric Company	Deepwater	181,000	Steam	Penns Grove, N. J.
Baltimore Gas & Electric Company	Gould Street	172,000	"	Baltimore, Md.
"	Riverside	330,000	"	"
"	Wagner	125,000	"	"
"	Westport	308,500	"	"
Delaware Power & Light Company	Edgemoor	195,000	"	Edgemoor, Del.
Jersey Central Power & Light Company	Sayreville	215,974	"	Sayreville, N. J.
"	Werner	118,750	"	South Amboy, N. J.
Metropolitan Edison Company	Crawford	117,500	"	Middletown, Pa.
"	Eyler	103,000	"	Reading, Pa.
"	Titus	225,000	"	"
New Jersey Power & Light Company	Gilbert	123,100	"	Holland, N. J.
Pennsylvania Electric Company	Front Street	118,750	"	Erie, Pa.
"	Seward	264,000	"	Seward, Pa.
"	Shawville	250,000	"	Shawville, Pa.
Pennsylvania Power & Light Company	Hauto	101,250	"	Hauto, Pa.
"	Holtwood	108,800	Hydro	Holtwood, Pa.
"	Martins Creek	265,000	Steam	Martins Creek, Pa.
"	Sunbury	375,000	"	Shamokin Dam, Pa.
Philadelphia Electric Company	Barbadoes	168,000	"	Norristown, Pa.
"	Chester	256,000	"	Chester, Pa.
"	Conowingo	252,000	Hydro	Conowingo, Md.
"	Cromby	350,000	Steam	Cromby, Pa.
"	Delaware	463,750	"	Philadelphia, Pa.
"	Richmond	450,000	"	"
"	Schuylkill	135,000	"	"
"	Southwark	300,000	"	"

TABLE F-5 (Continued)

PRINCIPAL UTILITY GENERATING PLANTS IN POWER SUPPLY AREA 5
December 31, 1957

Company	Plant Name	Capacity (Kilowatts)	Prime Mover	Location
Public Service Electric & Gas Company	Burlington	490,000	Steam	Burlington, N. J.
"	Essex	330,500	"	Newark, N. J.
"	Kearny A	312,000	"	Kearny, N. J.
"	Kearny B	300,000	"	"
"	Linden	450,000	"	Linden, N. J.
"	Marion	201,800	"	Jersey City, N. J.
"	Sewaren	470,000	"	Sewaren, N. J.
Safe Harbor Water Power Corporation	Safe Harbor	230,555	Hydro	Safe Harbor, Pa.

TABLE F-6

REQUIRED ADDITIONS TO GENERATING CAPACITY IN POWER SUPPLY AREA 5
1965-1980
(Megawatts)

	1965	1970	1975	1980
Estimated Peak Demand	14,340	17,760	21,720	26,100
Reserve Requirements /1	1,430	1,780	2,170	2,610
Total Capacity Requirements	15,770	19,540	23,890	28,710
Capacity Available for Load				
Existing Fuel-Electric Capacity, December 31, 1957	9,795	9,795	9,795	9,795
Scheduled Additions to Fuel-Electric Capacity by 1963	4,684	4,684	4,684	4,684
Estimated Cumulative Retirement of Fuel-Electric Capacity	1,359	2,481	2,761	3,035
Net Fuel-Electric Capacity	13,120	11,998	11,718	11,444
Existing Hydroelectric Capacity	687	687	687	687
Total Available Capacity	13,807	12,685	12,405	12,131
Additional Capacity Required	1,963	6,855	11,485	16,579

/1 Estimated at 10 percent of peak demand.

TABLE F-7

PAST AND ESTIMATED FUTURE UTILITY POWER REQUIREMENTS IN MARKET FOR HAWK MOUNTAIN PROJECT
1950-1980

Year	Energy for Load (Millions of Kwh)	Peak Demand (Megawatts)	Load Factor (Percent)
1950	1,921	426	51.6
1955	2,649	568	53.2
1956	2,832	575	56.1
1957	3,043	618	56.2
1958	3,178	613	59.2
1960	3,640	690	60.0
1965	4,770	900	60.5
1970	6,150	1,150	61.0
1975	7,740	1,440	61.5
1980	9,600	1,770	62.0

TABLE F-8

PAST AND ESTIMATED FUTURE DISTRIBUTION OF UTILITY ENERGY REQUIREMENTS IN MARKET AREA OF HAWK MOUNTAIN PROJECT BY CLASS OF SERVICE
1950-1980
(Millions of Kwh)

Year	Rural and Residential	Commercial	Industrial	All Other	Total Deliveries	Losses	Energy for Load
1950	621	302	602	111	1,636	285	1,921
1955	896	438	772	177	2,283	366	2,649
1956	1,001	480	819	184	2,484	348	2,832
1957	1,045	513	867	196	2,621	422	3,043
1958	1,123	552	846	217	2,738	440	3,178
1960	1,290	640	960	250	3,140	500	3,640
1965	1,780	850	1,160	330	4,120	650	4,770
1970	2,370	1,140	1,380	420	5,310	840	6,150
1975	3,070	1,470	1,630	520	6,690	1,050	7,740
1980	3,880	1,900	1,890	630	8,300	1,300	9,600

TABLE F-9

CAPACITY OF GENERATING PLANTS OF INTERCONNECTED SYSTEM OF NEW YORK STATE ELECTRIC & GAS CORPORATION
December 31, 1957
(Kilowatts)

Plant	Location	Installed Steam	Installed Hydro	Dependable
Colliers	Colliersville		3,560	800
Goudey	Binghamton	147,500		178,000
Greenidge	Dresden	160,000		206,000
Hickling	East Corning	70,000		90,000
Jennison	Bainbridge	60,000		76,000
Keuka	Keuka		2,000	2,000
Milliken	Ludlowville	135,000		150,000
Riverside	Elmira	21,500		21,000
Seneca Falls	Seneca Falls		8,000	7,100
Seneca Mills	Seneca Mills		240	-
Waterloo	Waterloo		1,920	1,600
	Total	594,000	15,720	732,500

TABLE F-10

REQUIRED ADDITIONS TO GENERATING CAPACITY IN MARKET AREA OF THE HAWK MOUNTAIN PROJECT
1965-1980
(Megawatts)

	1965	1970	1975	1980
Estimated Peak Demand	900	1,150	1,440	1,770
Reserve Requirements /1	108	138	173	212
Total Capacity Requirements	1,008	1,288	1,613	1,982
Total Capacity Available for Load				
Existing Steam-Electric Capacity, December 31, 1957	721	721	721	721
Scheduled Additions to Steam-Electric Capacity	270	270	270	270
Estimated Retirement of Steam-Electric Capacity	21	38	74	74
Net Steam-Electric Capacity	970	953	917	917
Existing Hydroelectric Capacity	12	12	12	12
Total Available Capacity	982	965	929	929
Additional Capacity Required	26	323	684	1,053

/1 Estimated at 12 percent of peak demand.

TABLE F-11

ESTIMATED LOW-TENSION BUS-BAR COST OF STEAM-ELECTRIC POWER
July 1, 1958

Item	Unit	Alternative Steam-Electric Plant Site: Portland, Pa.	Alternative Steam-Electric Plant Site: Bainbridge, N.Y.
A. Proposed Project		Tocks Island	Hawk Mt.
B. Basic Assumptions			
1. Unit Size	Kw	250,000	150,000
2. Unit Cost	$/Kw	170	160
3. Life of Plant	Years	35	35
4. Ave. Ann. Opera.	Hours	4,500	4,500
5. Fuel	Type	Coal	Coal
6. Fuel Cost (Per Million Btu)	Cents	36	36
7. Reserve Fuel Supply	Days	90	90
8. Total Net Heat Rate	Btu/Kwh	9,300	9,400
9. Incremental Heat Rate	Btu/Kwh	8,370	8,460
10. Total O. and M.	$/Kw/Yr.	2.55	2.95
11. Fixed O. and M. (Percent B-10)	%	65	65
12. Admin. and Gen. (Percent B-11)	%	25	25
13. Financing	Type	Private	Private
14. Fixed Charges			
a. Cost of Money	%	6.00	6.00
b. Depreciation (35 Yr. S.F.)	%	0.90	0.90
c. Interim Replacements	%	0.35	0.35
d. Insurance	%	0.25	0.25
e. Sub-total	%	7.50	7.50
f. Taxes			
1. Federal Income	%	3.69	2.81
2. Federal Misc.	%	0.10	0.10
3. State & Local	%	1.04	2.38
4. Total	%	4.83	5.29
g. Total Fixed Charges	%	12.33	12.79

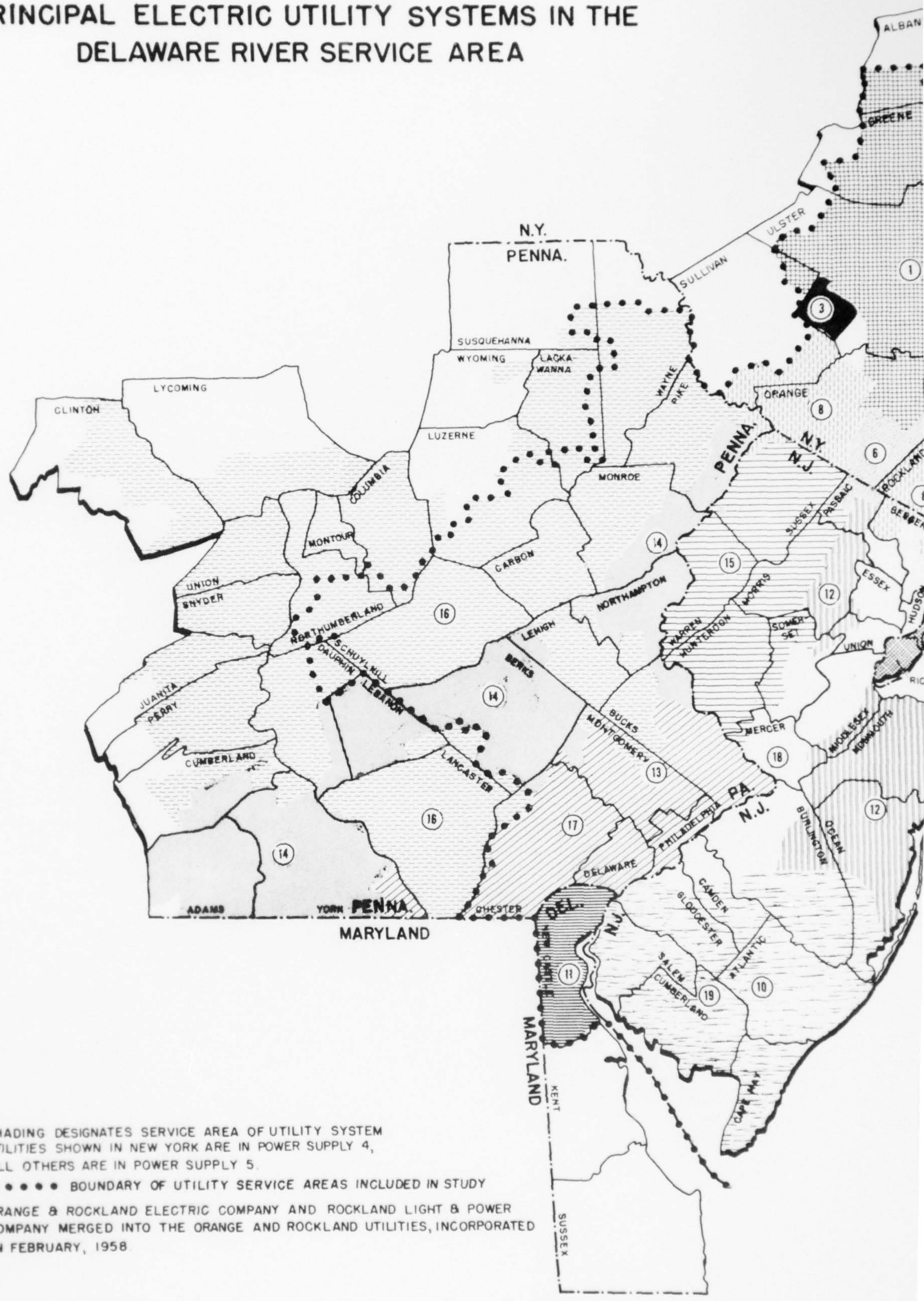
TABLE F-11 (Continued)

ESTIMATED LOW-TENSION BUS-BAR COST OF STEAM-ELECTRIC POWER
July 1, 1958

Item	Unit	Alternative Steam-Electric Plant Site: Portland, Pa.	Bainbridge, N.Y.
		Tocks Island	Hawk Mt.
C. Annual Capacity Cost			
1. Fixed Charges			
a. Cost of Money, Depreciation, Interim Replacements and Insurance	$/Kw/Yr.	12.75	12.00
b. Taxes	$/Kw/Yr.	8.21	8.46
c. Total	$/Kw/Yr.	20.96	20.46
2. Interest on Reserve Fuel Investment	$/Kw/Yr.	0.22	0.21
3. Fixed Operating Costs			
a. Fuel	$/Kw/Yr.	1.51	1.44
b. O. and M.	$/Kw/Yr.	1.65	1.90
c. Admin. and Gen.	$/Kw/Yr.	0.41	0.48
d. Total	$/Kw/Yr.	3.57	3.82
4. Total Annual Capacity Cost			
a. Calculated	$/Kw/Yr.	24.75	24.49
b. Use	$/Kw/Yr.	24.80	24.50
D. Variable Operating Costs			
1. Incremental Fuel	Mills/Kwh	3.01	2.88
2. O. and M.	Mills/Kwh	0.20	0.23
3. Total			
a. Calculated	Mills/Kwh	3.21	3.11
b. Use	Mills/Kwh	3.2	3.1

DELAWARE RIVER BASIN SURVEY

PRINCIPAL ELECTRIC UTILITY SYSTEMS IN THE DELAWARE RIVER SERVICE AREA



* SHADING DESIGNATES SERVICE AREA OF UTILITY SYSTEM
UTILITIES SHOWN IN NEW YORK ARE IN POWER SUPPLY 4,
ALL OTHERS ARE IN POWER SUPPLY 5.

● ● ● ● ● BOUNDARY OF UTILITY SERVICE AREAS INCLUDED IN STUDY

1/ ORANGE & ROCKLAND ELECTRIC COMPANY AND ROCKLAND LIGHT & POWER COMPANY MERGED INTO THE ORANGE AND ROCKLAND UTILITIES, INCORPORATED IN FEBRUARY, 1958.

AD-A043 793 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 8/6
REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)
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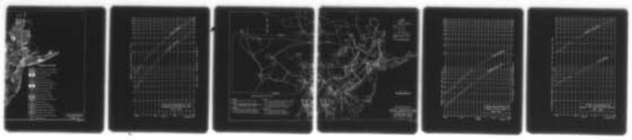

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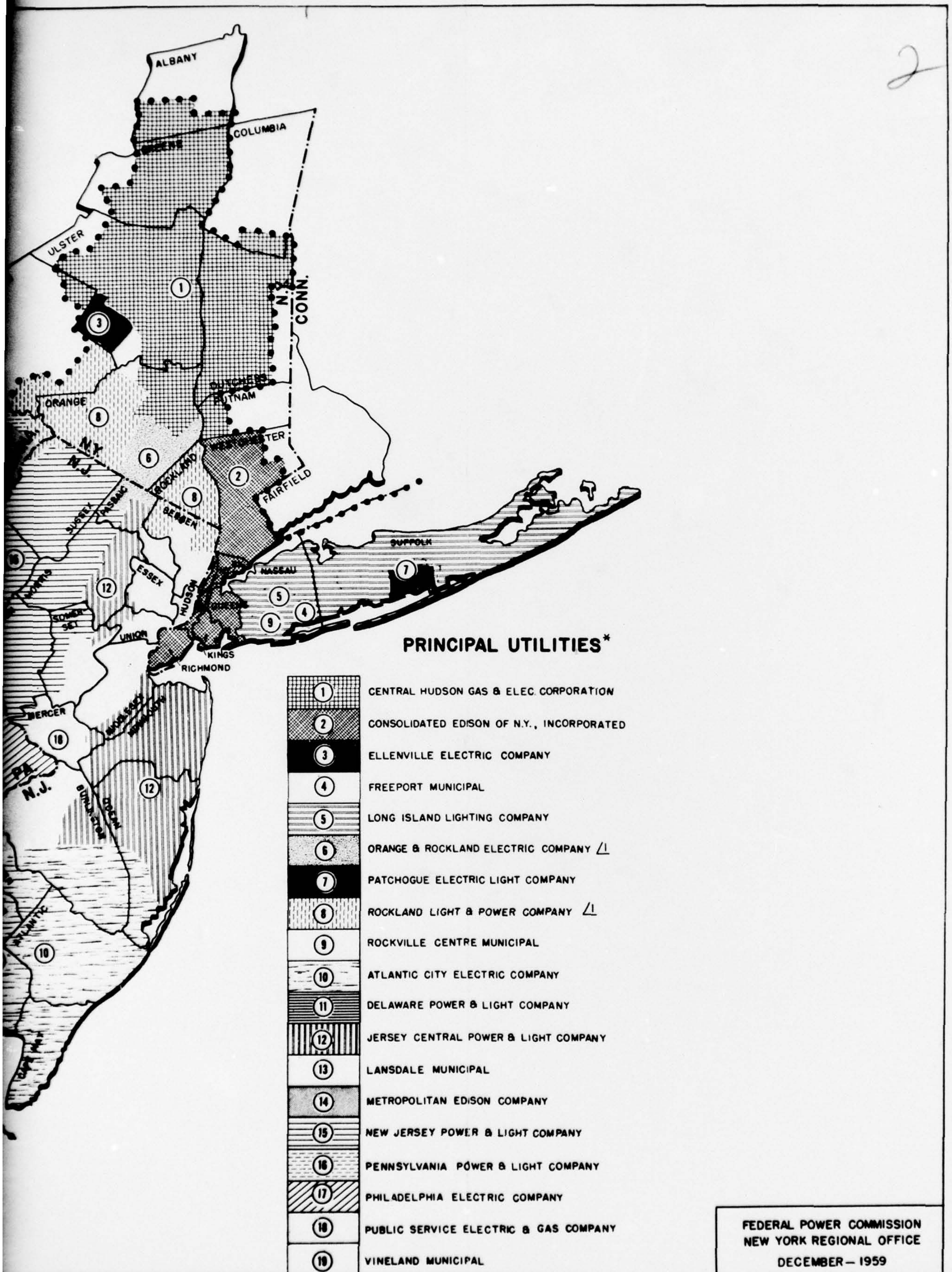
ALBANY
COLUMBIA
GREENE
ULSTER
N.Y.
CONN.
DUTCHESS
PUTNAM
ORANGE
N.Y.
N.J.
ROCKLAND
WESTCHESTER
FAIRFIELD
SUSSEX
PASSAIC
BERGEN
SUFFOLK
NASSAU
MORRIS
ESSEX
HUDSON
SOMERSET
UNION
KINGS
RICHMOND
MERCER
MIDDLESEX
MONMOUTH
PA.
N.J.
BURLINGTON
OCEAN
ATLANTIC
PRINCIPAL UTILITIES*
1 CENTRAL HUDSON GAS & ELEC. CORPORATION
2 CONSOLIDATED EDISON OF N.Y., INCORPORATED
3 ELLENVILLE ELECTRIC COMPANY
4 FREEPORT MUNICIPAL
5 LONG ISLAND LIGHTING COMPANY
6 ORANGE & ROCKLAND ELECTRIC COMPANY /1
7 PATCHOGUE ELECTRIC LIGHT COMPANY
8 ROCKLAND LIGHT & POWER COMPANY /1
9 ROCKVILLE CENTRE MUNICIPAL
10 ATLANTIC CITY ELECTRIC COMPANY
11 DELAWARE POWER & LIGHT COMPANY
12 JERSEY CENTRAL POWER & LIGHT COMPANY
13 LANSDALE MUNICIPAL
14 METROPOLITAN EDISON COMPANY
15 NEW JERSEY POWER & LIGHT COMPANY
16 PENNSYLVANIA POWER & LIGHT COMPANY
17 PHILADELPHIA ELECTRIC COMPANY
18 PUBLIC SERVICE ELECTRIC & GAS COMPANY
19 VINELAND MUNICIPAL
FEDERAL POWER COMMISSION
NEW YORK REGIONAL OFFICE
DECEMBER – 1959

PLATE F-1

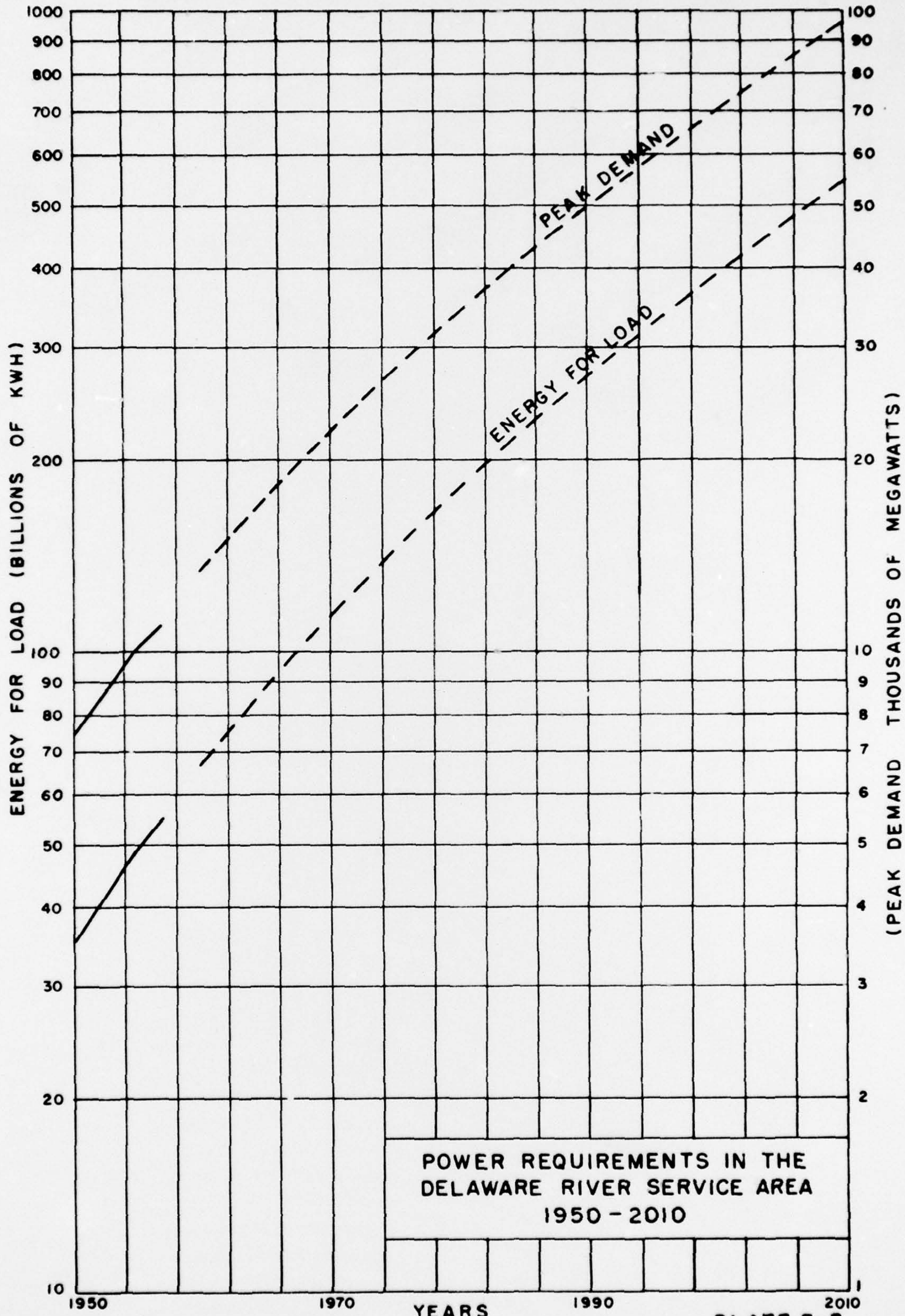
POWER REQUIREMENTS IN THE DELAWARE RIVER SERVICE AREA 1950 - 2010
ENERGY FOR LOAD (BILLIONS OF KWH)
(PEAK DEMAND THOUSANDS OF MEGAWATTS)
PEAK DEMAND
ENERGY FOR LOAD
YEARS
1950
1970
1990
2010
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
1
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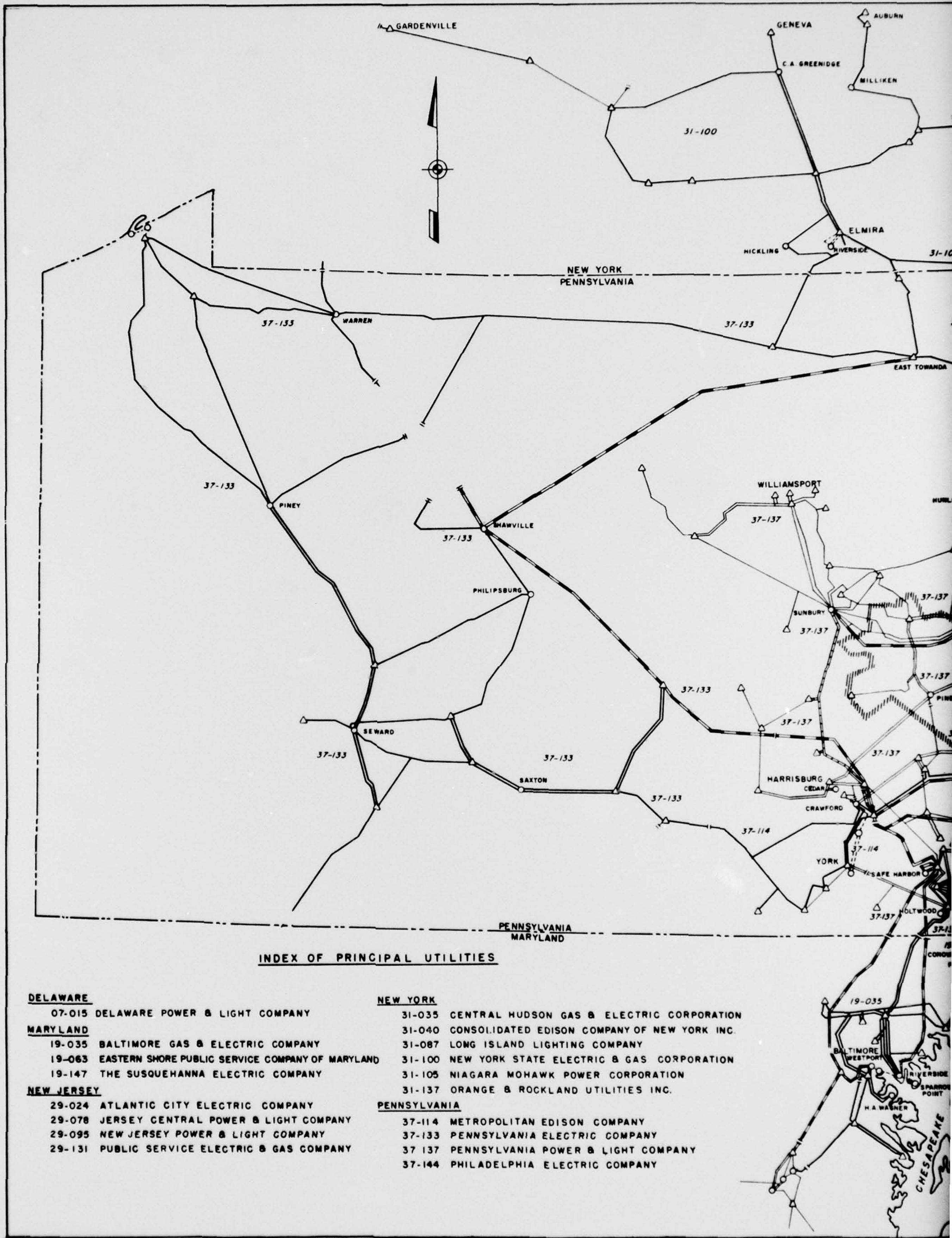
PLATE F-2



INDEX OF PRINCIPAL UTILITIES

DELAWARE

07-015 DELAWARE POWER & LIGHT COMPANY

MARYLAND

19-035 BALTIMORE GAS & ELECTRIC COMPANY
19-063 EASTERN SHORE PUBLIC SERVICE COMPANY OF MARYLAND
19-147 THE SUSQUEHANNA ELECTRIC COMPANY

NEW JERSEY

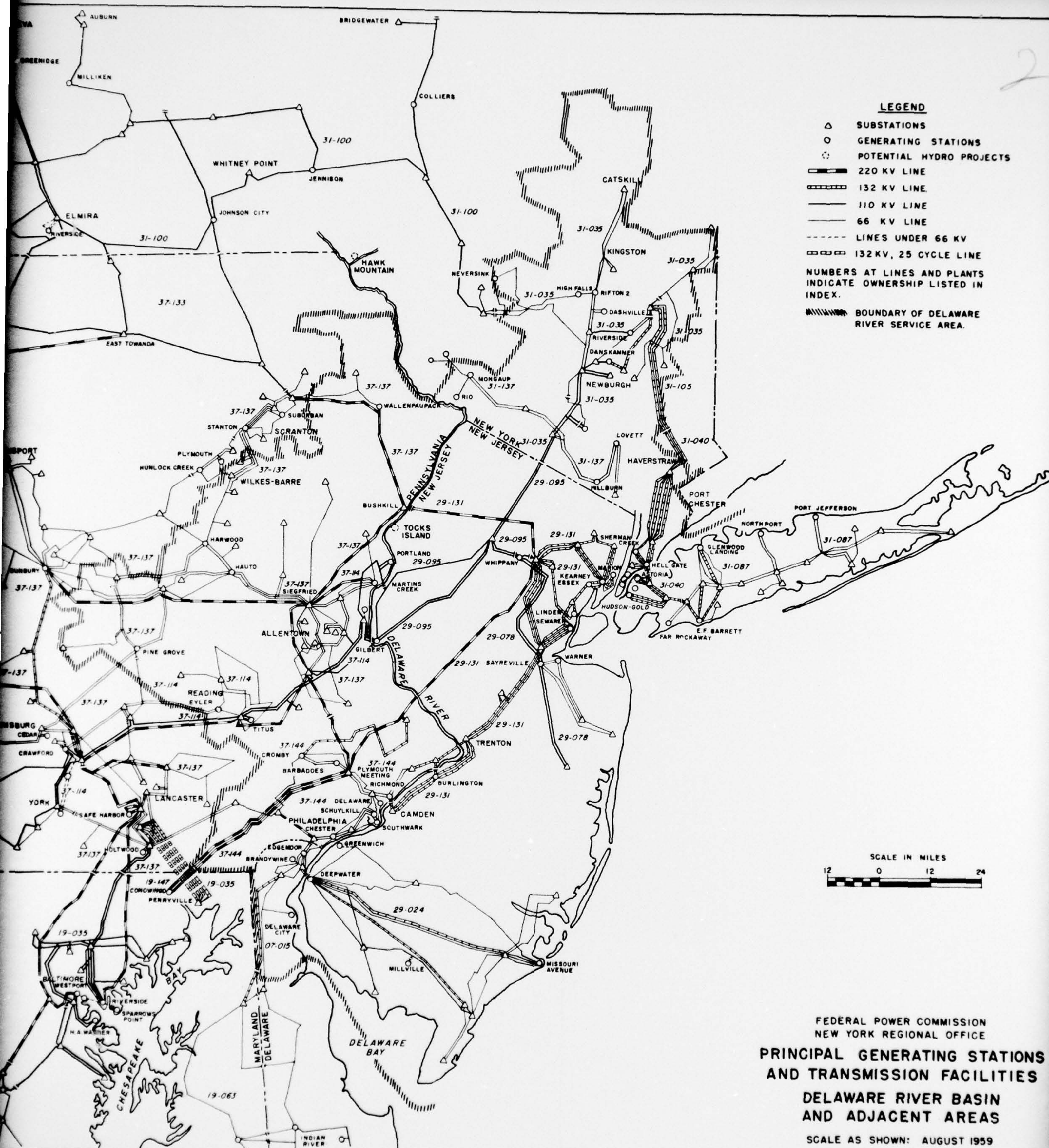
29-024 ATLANTIC CITY ELECTRIC COMPANY
29-078 JERSEY CENTRAL POWER & LIGHT COMPANY
29-095 NEW JERSEY POWER & LIGHT COMPANY
29-131 PUBLIC SERVICE ELECTRIC & GAS COMPANY

NEW YORK

31-035 CENTRAL HUDSON GAS & ELECTRIC CORPORATION
31-040 CONSOLIDATED EDISON COMPANY OF NEW YORK INC.
31-087 LONG ISLAND LIGHTING COMPANY
31-100 NEW YORK STATE ELECTRIC & GAS CORPORATION
31-105 NIAGARA MOHAWK POWER CORPORATION
31-137 ORANGE & ROCKLAND UTILITIES INC.

PENNSYLVANIA

37-114 METROPOLITAN EDISON COMPANY
37-133 PENNSYLVANIA ELECTRIC COMPANY
37 137 PENNSYLVANIA POWER & LIGHT COMPANY
37-144 PHILADELPHIA ELECTRIC COMPANY


LEGEND
SUBSTATIONS
GENERATING STATIONS
POTENTIAL HYDRO PROJECTS
220 KV LINE
132 KV LINE
110 KV LINE
66 KV LINE
LINES UNDER 66 KV
132 KV, 25 CYCLE LINE
NUMBERS AT LINES AND PLANTS INDICATE OWNERSHIP LISTED IN INDEX.
BOUNDARY OF DELAWARE RIVER SERVICE AREA.
SCALE IN MILES
12 0 12 24
FEDERAL POWER COMMISSION
NEW YORK REGIONAL OFFICE
PRINCIPAL GENERATING STATIONS AND TRANSMISSION FACILITIES
DELAWARE RIVER BASIN AND ADJACENT AREAS
SCALE AS SHOWN: AUGUST 1959
AUBURN
BRIDGEWATER
MILLIKEN
COLLIERS
WHITNEY POINT
JENNISON
JOHNSON CITY
ELMIRA
RIVERSIDE
CATSKILL
KINGSTON
HAWK MOUNTAIN
NEVERSINK
HIGH FALLS
RIFTON 2
DASHVILLE
RIVERSIDE
DANSKAMMER
NEWBURGH
MONGAUP
RIO
EAST TOWANDA
WALLENPAUPACK
SUBURBAN
STANTON
SCRANTON
PLYMOUTH
HUNLOCK CREEK
WILKES-BARRE
LOVETT
HAVERSTRAW
HILLBURN
PORT CHESTER
PORT JEFFERSON
NORTHPORT
GLENWOOD LANDING
NEW YORK
NEW JERSEY
PENNSYLVANIA
BUSHKILL
TOCKS ISLAND
PORTLAND
MARTINS CREEK
WHIPPANY
SHERMAN CREEK
HELL GATE
ASTORIA
KEARNEY
ESSEX
MARION
HUDSON-GOLD
LINDEN
SEWAREN
FAR ROCKAWAY
E.F. BARRETT
HARWOOD
HAUTO
SUNBURY
SIEGFRIED
ALLENTOWN
GILBERT
DELAWARE RIVER
PINE GROVE
READING
EYLER
TITUS
SAYREVILLE
WARNER
TRENTON
CROMBY
BARBADOES
PLYMOUTH MEETING
RICHMOND
BURLINGTON
CEDAR
CRAWFORD
YORK
LANCASTER
SAFE HARBOR
HOLTWOOD
PHILADELPHIA
DELAWARE
SCHUYLKILL
CHESTER
CAMDEN
SOUTHWARK
EDGEMOOR
BRANDYWINE
GREENWICH
DEEPWATER
CONOWINGO
PERRYVILLE
DELAWARE CITY
MILLVILLE
MISSOURI AVENUE
BALTIMORE
WESTPORT
RIVERSIDE
SPARROWS POINT
H.A. WAGNER
CHESAPEAKE BAY
DELAWARE BAY
MARYLAND
DELAWARE
INDIAN RIVER
31-100
37-133
31-035
31-105
31-040
31-137
37-137
37-114
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29-131
29-095
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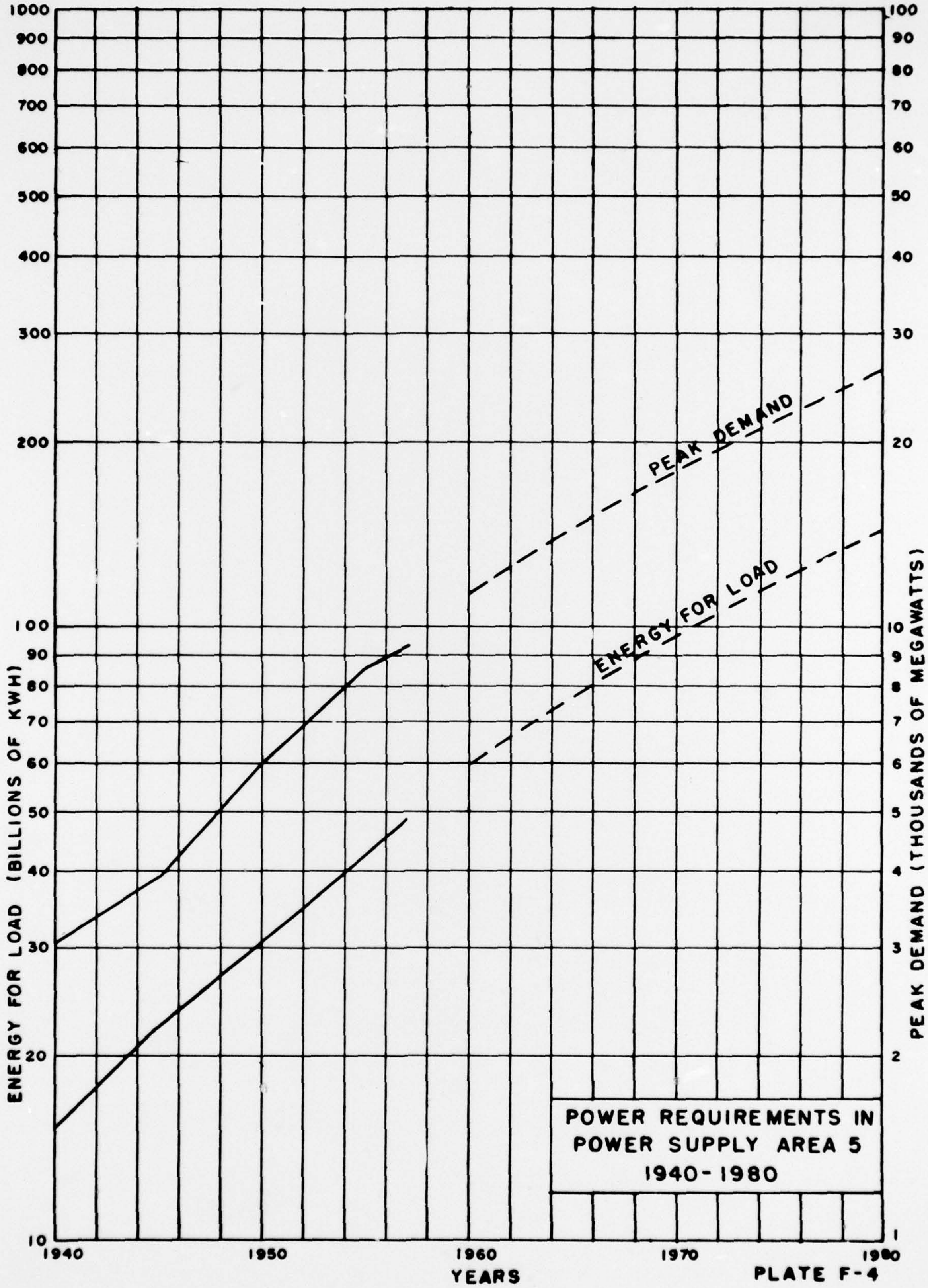
19-147
19-035
19-063
07-015

PLATE F-3



ENERGY FOR LOAD (BILLIONS OF KWH)
PEAK DEMAND (THOUSANDS OF MEGAWATTS)
1000
900
800
700
600
500
400
300
200
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60
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4
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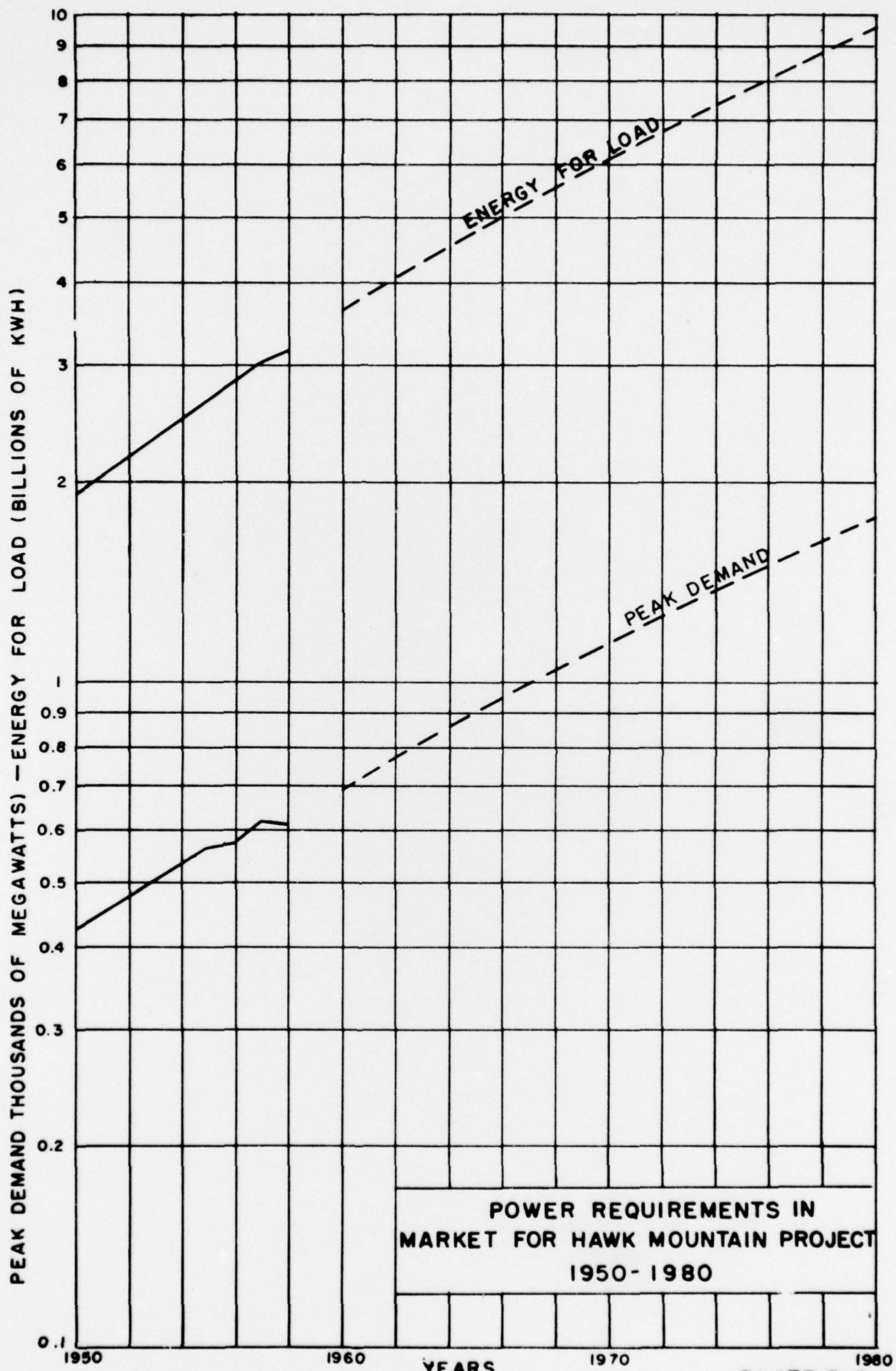
2
1
1940
1950
1960
1970
1980
YEARS
PEAK DEMAND
ENERGY FOR LOAD
POWER REQUIREMENTS IN
POWER SUPPLY AREA 5
1940-1980

PLATE F-4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6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
PEAK DEMAND THOUSANDS OF MEGAWATTS) —ENERGY FOR LOAD (BILLIONS OF KWH)
ENERGY FOR LOAD
PEAK DEMAND
POWER REQUIREMENTS IN
MARKET FOR HAWK MOUNTAIN PROJECT
1950-1980
1950
1960
1970
1980
YEARS

PLATE F-5